INCREASING YIELD OF LATE-PLANTED SOYBEAN THROUGH MANAGEMENT PRACTICES IN THE SOUTHERN GREAT PLAINS

By

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Abstract: Increased soybean commodity prices and high-yielding cultivars have instigated producers to expand soybean production outside traditional regions. Introduction of soybean to relatively new areas such as the Southern Great Plains, has created the need for management practices unique to the region to exploit full yield potential in these environments. Oklahoma soybean production, for instance, frequently results in low yields due its adverse environmental conditions, along with common late-plantings, as a double crop following wheat harvest. Due to soybean photoperiod sensitivity, delayed planting leads to a shortened vegetative growth period, which potentially reduces seed yield. The influence of management practices, such as seeding rate, row spacing, maturity group selection, starter and foliar fertilization, irrigation, and the use of long juvenile soybean lines, on late-planted soybean yields has not yet been evaluated in the Southern Great Plains. The objectives of this study are to evaluate the effect of these specific management strategies on late-planted soybean yields and their potential adoption in the Southern Great Plains to minimize yield losses in these late production systems. Four different field studies were established on late plantings in Oklahoma as followed by numbers 1, 2, 3, and 4: **1)** Four seeding rates ranging from 198,000 to 383,000 seeds ha^{-1}, three row spacings (19, 38, and 76 cm) and two maturity groups (4.8 and 5.6) under rainfed conditions. Seed yield, plant population, canopy cover, and partial economic return were analyzed. Seed yield was not affected by seeding density, but yield results for 38 and 76 cm row spacings showed slight advantage to 19 cm rows. Partial economic return of 38 and 76 cm rows ranged from 13 to 25% greater than 19 cm row spacing, with the greatest returns at the lowest seeding densities. **2)** Three soybean lines from maturity group (MG) 6, 7, and 8 carrying the long juvenile trait (LJ) were compared to three high-yielding varieties from MG 3, 4, and 5, in four planting dates from late-May to late-June. Vegetative growth period, canopy cover, seed yield, and seed quality were evaluated. Long juvenile soybean lines had greater growth but similar yields compared to non LJ varieties, due to the extended growth period overlapping early reproductive stages diminishing seed production potential. **3)** Fertilization strategies including two starter and four foliar treatments were compared to a control treatment with no fertilizer applied. Starter or foliar treatments resulted in no seed yield differences compared to control treatment. **4)** Soybean from MGs 4.8 and 5.6 were sown in 19 and 76 cm row spacings at three seeding rates (247,000, 346,000, and 445,000 seeds ha^{-1} were tested under irrigated conditions and seed yield evaluated. Seed yield of late-planted soybean under irrigation was affected only by MG. Seeding rate and row spacing had no effect on yield. Average yield of MG 4.8, across row spacings and years was 2620 kg ha^{-1}, which was 25 % greater than MG 5.6 yield (1980 kg ha^{-1}).

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER II

Table Page

CHAPTER III

Table Page

CHAPTER IV

Table Page

CHAPTER V

Table Page

LIST OF FIGURES

CHAPTER I

CHAPTER II

CHAPTER III

Figure Page

CHAPTER IV

Figure Page

CHAPTER V

Figure Page

CHAPTER I

GENERAL INTRODUCTION

1.1. U.S. Soybean Production Aspects

Soybean is the dominant oilseed crop currently produced and consumed in the world. In the United States, soybean accounts for 90% of total oilseed production, with a total annual production of ~82 million tons (NASS-USDA, 2013). It is the second most planted field crop in the U.S., following corn, with 31.2 million hectares planted in 2013 (NASS-USDA, 2013). More than 80% of this production has been concentrated in the Midwest and Mississippi Valley regions where climate conditions are favorable for soybean growth and development. These areas usually have favorable rainfall amounts and distribution and moderate summer temperatures (Boerma and Specht, 2004). Although there are many soybean varieties adapted to areas with warmer and drier climates, the production and yields are still limited in these environments. Nonetheless, good soybean commodity prices and high-yielding cultivars have stimulated producers to grow this crop outside of traditional production regions, contributing to a greater overall production. The U.S. soybean planted area significantly increased from 23.4 million ha in 1990 to 31.2 million ha in 2013 (NASS-USDA, 2013). Following the same trend, the Southern Great Plains region (Texas, Oklahoma, and Kansas), with most of its area outside the traditional soybean growing region, has been showing significant increase in soybean production. Planted area increased from approximately 1 mi hectares to 1.64 mi hectares during the same period. Oklahoma increased from 101,200 to 182,100 ha for the same period, with total soybean hectarage production of around 297,600 tons in 2013 (NASS-USDA, 2013).

Introduction of soybean to relatively new areas has created the need for management practices unique to the Southern Great Plains region. Oklahoma soybean production, for instance, has been historically located in the northern and eastern part of the state, but soybean production has expanded further west into drier climates, which frequently results in low yield. Late planted soybean also contribute to lower yields in Oklahoma, and double-crop soybean planted after wheat harvest is an example of this scenario. Due to soybean photoperiod sensitivity, these delayed plantings lead to a shorted time for soybean plants to complete their growth. In these cases, critical development phases will likely coincide with periods of hot and dry environmental conditions, which will potentially negatively impact soybean yield (Egli and Bruening, 2000; Wesley, 1999; Knapp et al., 1980). Therefore, better management practices are required for late-sown soybean in Oklahoma to minimize yield losses and to optimize profits. There are several management practices that might be feasible to improve yield of late-planted soybean. Seeding rate, row spacing, maturity group selection, irrigation, and fertilization are management practices that will be discussed in this manuscript.

Currently a minimum amount of data exists regarding management practices for the Southern Great Plains. Existing planting date recommendations range from as early in April as possible when sowing maturity group (MG) 3 or early MG 4 cultivars, until early June when late MG IV and V are used. Planting soybean after mid-June has shown significant reduction in yield potential (Barreiro and Godsey, 2013). These same authors indicated a 1-2% drop in yield potential for every day when planting is delayed after June 15. With the majority of the soybean crop in Oklahoma planted after the harvest of winter wheat (*Triticum aestivum* L.), often times soybean planting occurs after June 15. The consequences of this practice are usually poor stands and low yields, even when adequate fertilization is provided (Kane et al., 1997; Wesley, 1999). Knapp et al. (1999) reported that reduction in yield of late-planted soybean in the Mid-South is related to shorter days, lower solar radiation, low air temperatures, and less soil moisture availability at the end the growing stage. Egli and Bruening (2000) found similar results in Kentucky. Time-limited soybean crops due to late planting in the mid-south of the United States have greater risks of undergoing drought stress at critical development stages, which is a frequent yield reducing factor (Kane et al., 1997). Although Purcell et al. (2002) stated that the use of full-season MG soybean in double cropping results in adequate time frame for vegetative growth and canopy closure when sown at recommended population, Heatherly et al. (2005) found that late planting dates with late MG often cause a delay in the reproductive development and increases risks of reduced grain yield due to drought stress, higher pest and disease pressure, and late-season seed and foliar diseases.

When selecting a planting date and maturity group, the two most important environmental factors that must be considered are photoperiod and temperature requirements. This interaction has a great influence in how soybean producers must manage their soybean crop to be able to match flowering and maturity dates to periods less prone to environmental stresses, resulting in better grain yields (Alliprandini et al., 2009; Purcell, 2000).

1.2. Soybean Photoperiod and Temperature

Soybean is classified as a short-day photoperiod-sensitive plant, meaning that the crop remains in vegetative stage during long daylight hours and begins to flower when day length becomes shorter (Caviness and Thomas, 1979). In other words, flowering initiates after the period of darkness becomes equal to or greater than the critical night length (Board and Hall, 1984). The longest day of the year for the northern hemisphere is June 21st; then, nights become longer after this date (Withrow, 1959). The plants will flower during this period of longer nights when a certain number of uninterrupted hours of darkness (critical night length) is reached. For soybean cultivars adapted to the Oklahoma environment, the critical night length is around 10 hours (14 hours of daylight). Figure 1 shows three examples of day/night length according to location, helping to explain the interaction between photoperiod and time of the year, and reinforcing the reason why soybean producers must take it in consideration before planting their crop.

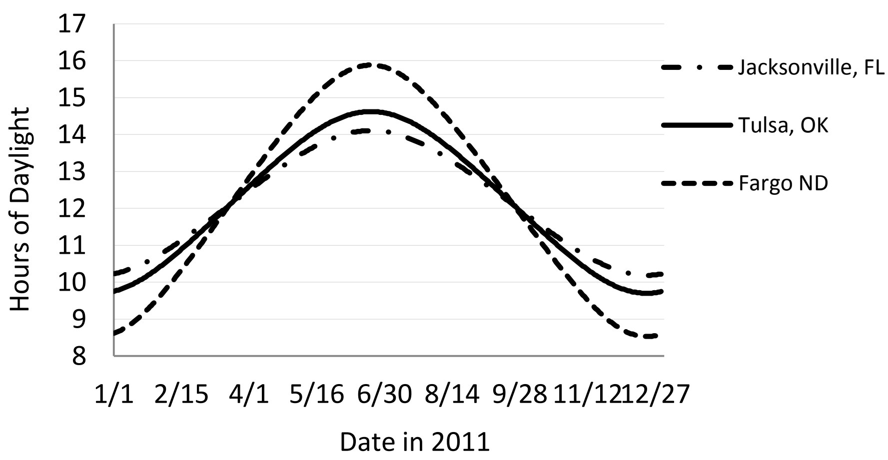

Figure 1. Relationship between daylength and time of the year for three locations in US.

For the three locations shown in Figure 1, daylight starts to increase and night length becomes shorter after March 20th. On June 21st, nights start to become longer until finally, on September 23rd, night time hours exceed daylight hours. Between June 21st and Sep 23rd, period of increasing night lengths and decreasing day period, is when soybean plants receive their stimulus to flower because critical night length is reached. For example, soybean varieties grown in Tulsa, OK usually require a critical daylength of 14 hours, so they would flower around July 27th. In summary, late-planted soybean flowering may be induced when little vegetative development has been achieved. With little biomass accumulation, soybean does not have enough resources to fill pods, resulting in low yield.

Along with photoperiod, temperature is also well known to directly affect the inducement of soybean developmental stages (Zhang et al., 2001). The optimum temperature for soybean growth and development is approximately 30˚C (Schlenker and Roberts, 2008). Soybean plants exposed for a few days to temperatures between 32 ˚C and 36 ˚C can survive this heat stress if accompanied with adequate water, otherwise, heat injury starts to appear. Frequent days over 37 ˚C and without water supply, however, can have a severe negative impact on the yield potential for the soybean crop (Godsey, 2011). During soybean seed filling, extreme temperatures can alter seed composition, vigor, viability, and reduce yield (Dornbos and Mullen, 1992). According to Foroud et al. (1993), excessive heat and drought stress at late reproductive stages of soybean development can cause reduction of the number of pods per plant, which will lead to a reduction in yield.

1.3.Soybean Row Spacing and Seeding Rate

In addition to yield reduction from short growing period, drought stress, and early frost damage risks, yield of late-sown soybean can also be reduced by improper MG, plant population, row spacing, or light interception (Purcell, 2000). Soybean production began to switch from large (≥ 76 cm) to narrow row spacing (< 76 cm) in the early 1990's. The benefits of narrow row spacing compared to wide row spacing have been well documented (Beatty et al., 1982; Copper, 1977; Ethredge et al., 1989; Lehman and Lambert, 1960; Parks et al.; 1982; and Weber et al., 1966). Among the benefits of narrow row spacing, potential for increasing plant density is an important characteristic. However, the introduction and wide use of glyphosate-resistant soybean cultivars since 1996, led to a significantly increase in soybean seed costs. In 2011, 94% of the total area sowed to soybean in the United States accounted for glyphosate-resistant soybean production (NASS-USDA, 2012). This generated a special attention in reaching optimum plant population to maximize yield and reduce seed costs (Lee et al., 2008).

Although many researchers have reported great potential in increasing soybean yields by narrowing row spacing, the adoption of this practice is not completely adopted due to the low yield response in corn (*Zea mays* L.) yields when planted at narrow row spacing (Hallman and Lowenberg-DeBoer, 1999; Westgate et al., 1997). By adopting narrow-spacing soybean, producers would have to constantly change their planter's row spacing since many alternate soybean and corn production. Although there are planters with technology where soybean and corn production can be planted using the same equipment just by raising additional row units, high costs for this technology and the uncertain increase in yield may prevent producers from this investment (De Bruin and Pederson, 2008). While soybean production being conducted under narrow row spacing has proved its benefits, some studies document that the increase in yields is genotype dependent (Grau et al., 1994; Weber et al. 1966), year and location (Lueschen et al., 1992), and planting date along with tillage system (Oplinger and Philbrook, 1992). An important advantage of managing soybean at narrow row spacing is the greater light interception due to the increase in canopy leaf area, since plants are more equidistant. Increased light interception by the plants leads to greater dry matter production, which ultimately may translate to greater seed yields (Shibles and Weber, 1966; Weber et al., 1966). Furthermore, when soybean canopy closure is achieved sooner at narrow row spacing weed control (Siemens and Oschwald, 1978; Buhler et al., 1990; Yelverton and Coble, 1991; Norsworthy and Oliver, 2009; Edwards and Purcell 2005) and soil moisture conservation can be increased (Elmore, 1987).

Besides the effect of row spacing on soybean yield, seeding rate also affects yield (Edwards and Purcell 2005, Board, 2000; Etheredge et al., 1989; Parvez et al., 1989; Egli 1988; Cooper, 1977; Shibles and Weber, 1966; Wiggans, 1939). Researches such as Philbrook et al. (1991) and Oplinger and Philbrook (1992) demonstrated that soybean yield can be significantly impacted by poor emergence and final stand. Thus, increasing seeding rate is a common strategy to overcome this yield loss. Through narrowing row spacing, optimum seeding rate can be potentially increased since the area is being maximized (Oplinger and Philbrook, 1992; Weber et al., 1966). However excessive increase in plant population can also decrease light interception efficiency since plant leaf area is decreased (Board, 2000; Edwards et al., 2005; Purcell et al., 2002). Another important reason for poor soybean yield performance at very high seeding densities is the increased propensity of lodging, which can reduce yield as much as 22% (Noor and Caviness, 1980). At high population densities, competition for solar radiation generally results in taller soybean plants and with thinner stems compared to plants at reduced populations; therefore, these plants are more likely to lodge (Cooper 1981; Mancuso and Caviness, 1991). Lodging in tall soybean plants also can be aggravated by heavy rainfalls and strong winds (Board 2001).

1.4. Soybean Water Deficit Stress and Irrigation

The effect of water deficit stress on soybean growth and yield is well known to depend on the level of stress and on the growth stage occurring the stress (Hsiao and Acevedo, 1974; Lewis et al., 1974; Sullivan and Eastin, 1974; Sionit and Kramer, 1977). The most critical periods for water stress in soybean are during pod formation (Sionit and Kramer, 1977) and pod filling (Doss et al., 1974). Water deficits usually occur due to decreasing rainfall and increasing evapotranspiration as the growing season progresses. Warmer days lead to greater transpiration, creating a plant water tension that increases water uptake from the soil (Heatherly, 1999). If water cannot be absorbed rapid enough by the roots, tension in the leaves will increase becoming a growth-limiting factor. As pod formation and filling are both sensitive to water stress occurring later in the season when rainfalls are at very low levels, soybean plants have significant potential for growth and development to be impacted under these conditions (Heatherly, 1999). The degree of impact depends on the duration of water deficit stress (Hodges and Heatherly, 1983), which can easily extend for many successive days in Oklahoma.

This soybean sensitivity for water deficits, especially during reproductive stages, reinforces the importance of irrigation when available during this period. Continued irrigation during these reproductive stages is essential (Griffin et al., 1985; Reicosky and Heatherly 1990; Heatherly and Spurlock, 1993) so that soil moisture is readily available for absorption until seeds are near full size, avoiding potential impacts on seed production. In other words, irrigation contributes to maximizing seed number and weight in soybean plants (Heatherly, 1999). Later MG cultivars potentially require greater irrigation as their critical stages (seed filling) usually fall on the most hot and dry periods of the growing season (Heatherly, 1999).

1.5. Soybean Foliar Fertilization

Soybean fertilization with N, P, K, and other nutrients can affect growth, yield, protein, and oil concentration (Mallarino and Haq, 2005); however, soybean has been considered to have low response to N, P, and K fertilization compared with other grain crops (Kamprath, 1974). Although N fertilization is not a common practice in soybean, since it obtains most of the N through symbiotic fixation, there are studies reporting that biosynthesized N is not always sufficient for maximum grain yield. (Weber, 1966; Wesley et al., 1998). Several studies have reported that application of N as a starter fertilizer increased soybean growth and grain yield (Afza et al., 1987; Al-Ithawi et al., 1980; Eaglesham et al., 1983; Osborne and Riedell, 2006; Sorensen and Penas, 1978; Touchton and Rickerl, 1986; Wood et al., 1993); however, other investigators have documented no response or negative response to N fertilization (Beard and Hoover, 1971; Deibert et al., 1979, Peterson and Varvel, 1989; Welch et al., 1973). In late-planted soybean environments, which are usually associated with double-cropping (Egli, 1976; Lewis and Phillips, 1976), grain yield reduction is related to insufficient vegetative growth (Boerma et al., 1982). As starter N can contribute to rapid soybean seedling growth, it may be a feasible practice for increasing grain yield in late-planted systems. On the other hand, Touchton and Rickerl (1986) stated that the chances of increasing grain yield with starter fertilizers in soybean are reduced as planting date is delayed.

Foliar fertilization of plants is a well-known practice that is been used for over 100 yr (Borkert, 1987). With soybean, this practice has been broadly studied since the early 1970’s. Most of these studies have addressed foliar fertilization of soybean during reproductive stages. During this phase, it is common to have a reduction in root activitiy and increased depletion of nutrients and metabolites from other plant tissues being transferred to the seeds (Hanway, 1976); therefore, supplementation of nutrients such as N, P, K, and S by foliar application during pod-filling can increase yields up to 31% (Garcia and Hanway, 1976).

Little research has focused on foliar fertilization of soybean during vegetative stages. Rosolem (1982) found no seed yield increase when applying foliar fertilizers containing different NPK rates with or without micronutrients with 30 to 75 d after emergence. At early critical stages; however, foliar application of small amounts could have favorable results if considered as a complement to soil fertility, especially for late planted soybean, where it could compensate for inadequate plant growth due to photoperiod sensitivity. In the Southern Great Plains, there is little research and limited data related to starter and foliar fertilization of soybean, and no studies were found covering these practices on late-planted soybean system.

CHAPTER II

LATE-PLANTED SOYBEAN YIELD AS AFFECTED BY ROW SPACING, SEEDING RATE, AND MATURITY GROUP IN THE SOUTHERN GREAT PLAINS

2.1. INTRODUCTION

Increased soybean commodity prices and high-yielding cultivars have caused producers to expand soybean cultivation outside traditional production regions. Introduction of soybean to relatively new areas such as the Southern Great Plains, has created the need for management practices unique to the region. Oklahoma soybean production, for instance, has been historically located in the northern and eastern part of the state, but soybean hectarage has expanded further west into drier climates, which frequently results in low yield. Along with adverse environmental conditions, late-planted soybean has been another common practice contributing to lower yields in Oklahoma. Winter wheat is the dominant cropping system; thus, soybean is often planted late as a double crop following wheat harvest (Barreiro and Godsey, 2013). Due to soybean photoperiod sensitivity, delayed planting leads to a shortened time for soybean plants to complete vegetative growth. In these cases, critical reproductive development phases will likely coincide with periods of hot and dry environmental conditions, which will potentially negatively impact soybean yield (Torres et al., 2013; Egli and Bruening, 2000; Wesley, 1999; Knapp et al., 1980). Therefore, better management practices are required for late-sown soybean in Oklahoma to minimize yield losses and to optimize profits. Seeding rate, row spacing, and maturity group selection are management practices that might improve yield of late-planted soybean and will be discussed in this manuscript.

Soybean production began to switch from wide (≥ 76 cm) to narrow row spacing (< 76 cm) in the early 1990's. The benefits of narrow row spacing compared to wide row spacing have been well documented (Beatty et al., 1982; Copper, 1977; Ethredge et al., 1989; Lehman and Lambert, 1960; Parks et al.; 1982; and Weber et al., 1966), in which potential for increase plant density and seed yield is the main characteristic. However, the introduction and wide spread use of glyphosate-resistant soybean cultivars since 1996 led to a significantly increase in soybean seed costs. In 2013, 94% of the total area sown to soybean in the United States was glyphosate-resistant (NASS-USDA, 2014). Higher seed costs generated interest in reaching optimum plant population to maximize yield while reducing seed costs (Lee et al., 2008).

Although many researchers have reported potential for increasing soybean yield by narrowing row spacing, this practice is not completely adopted due to the low response of corn (*Zea mays* L.) yield when planted in narrow rows (Hallman and Lowenberg-DeBoer, 1999; Westgate et al., 1997). Since many producers alternate soybean and corn production, adopting narrow-spacing soybean would result in the need to constantly change their planter's row spacing or purchase higher cost equipment with additional row units for easy transaction between wide and narrow rows (De Bruin and Pederson, 2008). An important advantage of managing soybean at narrow row spacing is light interception due to increased canopy leaf area, since plants are more equidistant. Increased light interception by the plants leads to greater dry matter production, which ultimately may translate to greater seed yields (Shibles and Weber, 1966; Weber et al., 1966). Furthermore, when soybean canopy closure is achieved sooner due to narrow row spacing, weed control (Siemens and Oschwald, 1978; Buhler et al., 1990; Yelverton and Coble, 1991; Norsworthy and Oliver, 2009; Edwards and Purcell 2005) and soil moisture conservation can be increased (Elmore, 1987). While soybean production being conducted under narrow row spacing has proved its benefits, some studies document that the yield increase is dependent on genotype (Grau et al., 1994; Weber et al. 1966), year and location (Lueschen et al., 1992), and planting date along with tillage system (Oplinger and Philbrook, 1992).

Besides the effect of row spacing on soybean yield, seeding rate also affects yield (Edwards and Purcell 2005, Board, 2000; Etheredge et al., 1989; Parvez et al., 1989; Egli 1988; Cooper, 1977; Shibles and Weber, 1966; Wiggans, 1939). Researches such as Philbrook et al. (1991), Oplinger and Philbrook (1992), and Popp et al. (2006) demonstrated that soybean yield can be significantly impacted by poor emergence and final stand and, increasing seeding rate is a common strategy to overcome this source of yield loss. Through narrowing row spacing, optimum seeding rate can be potentially increased since the use of ground area is being maximized (Oplinger and Philbrook, 1992; Weber et al., 1966); however, excessive increase in plant population can also decrease light interception efficiency since plant leaf area is decreased (Board, 2000; Edwards et al., 2005; Purcell et al., 2002). Another important reason for poor soybean yield at very high seeding densities is the increased propensity for lodging, which can reduce yield as much as 22% (Noor and Caviness, 1980). At high population densities, competition for solar radiation generally results in taller soybean plants and with thinner stems compared to plants at reduced populations; therefore, these plants are more likely to lodge (Cooper 1981; Mancuso and Caviness, 1991). Lodging in tall soybean plants also can be aggravated by heavy rainfalls and strong winds (Board 2001), which are common occurrences late in the growing season for the Southern Great Plains.

Soybean canopy at specific row spacing is well known to depend on plant density and leaf expansion (Girardin and Tollenaar, 1994; Loomis et al., 1968; Tetio-Kagho and Gardner, 1988). Accordingly, soybean plants present greater branching and leaf area production at reduced plant density, which favors greater light interception per plant compared to increased plant density (Forountan-pour et al., 1999; Weber et al., 1966). Many studies have been conducted over time to determine optimum row spacing and seeding densities for soybean production according to the environment and maturity group involved. However, these characteristics have not yet been studied in late-planted soybean systems in the Southern Great Plains. Therefore, the objectives of this study were to determine the optimum soybean maturity group, row spacing and seeding rate to establish adequate plant population to reach optimal yield in late-planted systems under rainfed conditions in the Southern Great Plains.

2.2. MATERIAL AND METHODS

Seven site-years were included in this study: Stillwater, OK (2011, 2012, and 2013), Haskell, OK (2011 and 2013), Lahoma, OK (2012), and Perkins, OK (2013). In Stillwater, the trial was established on an Ashport Silt Clay Loam (fine-silty, mixed, superactive, thermic Fluventic Haplustolls) located at the Oklahoma State University (OSU) Agronomy Research Station (36°23’21.28” N, 97°06’34.69” W, elevation 268 m). In Haskell, the trial was located at the OSU Eastern Research Station (35°44’44.10” N, 95°38’07.63” W, elevation 178 m) on a Taloka Silt Loam (fine, mixed, active, thermic Mollic Albaqualfs). In Lahoma, experimental area was located at the OSU North Central Research Station (36°07’03.15” N, 97°05’47.85” W, elevation 390 m) on a Grant Silt Loam (fine-silty, mixed, superactive, thermic Udic Argiustolls) soil. In Perkins, the trial was established on a Teller Fine Sandy Loam (fine-loamy, mixed, thermic, Udic Argiustoll) located at the OSU Cimarron Valley Research Station (36°59’26.00” N, 97°02’05.98” W, elevation 281 m).

The experimental design was a three-way factorial arrangement within a RCBD with three replications. Factors consisted of two cultivars of different maturity groups (MG, 4.8 and 5.6), three row spacings (19, 38, and 76 cm), and four seeding rates (198,000, 260,000, 321,000, and 383,000 seeds ha^{-1}). Plots were 3 m wide by 7.6 m long, accounting for 4, 8, or 14 rows per plot, depending on row spacing. No pesticide seed treatments were used in this study. Planting dates for each year and location are shown in Table 1. Average rainfall and temperatures during each growing season (Jun – Oct) were recorded by the nearest Mesonet stations, which were 400, 800, and 1500 m away from the trials at Stillwater, Perkins, and Haskell, respectively. Mesonet is a world class environmental monitoring network across the state of Oklahoma. Measured averages and their deviation from 30-yr average are displayed in Table 2.

Based on the yield performance from previous studies in Oklahoma (Barreiro and Godsey, 2013), glyphosate resistant soybean cultivars "REV48R22" (MG 4.8) and "AG5632" (MG 5.6) were selected to be used at all locations. The cultivar REV48R22 has an indeterminate growth habit, so flowering lasts for several weeks and overlaps early reproductive stages. The cultivar AG5632 has a determinate growth habit, so flowering happens quickly lasting few days. Plots at all site-years were sown 2.5 cm deep using a Hedge small-plot, conventional-drill (Winterstieger, Salt Lake City, UT) for 19 cm row spacing, or a Monosem vacuum planter (Monosem, Inc. Edwardsville, KS) with four rows for the 38 cm and 76 cm row spacing treatments. Prior to planting, soybean seeds were inoculated with *Bradyrhisobium japonicum* (EMD BioScience, Brookfield, WI). Soil samples were taken from each year to determine fertilization requirements. Based on these results (data not shown) and the Oklahoma State University Cooperative Extension recommendations, no additional soil fertilization was required at any site (Pratt et al., 2009). Weed and insect management practices were also conducted according to Oklahoma State University recommended practices (Pratt et al., 2009), which included a pre-emergence application of 2.2 kg ha^{-1} metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] and 0.8 kg ha^{-1} pendimethalin N-(1-ethylpropyl)- 3,4-dimethyl-2,6-dinitrobenzenamine, plus a single post-emergence application of 1.12 kg ha^{-1} glyphosate [N-(phosphonomethyl) glycine3]. Insect control was necessary only at Stillwater site in 2013 and consisted of a single application of 0.028 kg ha-1 lambda-cyhalothrin to suppress a green cloverworm (Hypena scabra) infestation.

Extremely hot and dry conditions observed in 2011 and 2012 resulted in loss of Stillwater and Lahoma sites, respectively. In 2012 and 2013 the Stillwater site was equipped with irrigation to supplement rainfall deficits to bring totals closer to the 30-yr average. The goal of this supplemental irrigation was to simulate a thypical soybean production year at Stillwater. Irrigation occurred weekly and water amounts were the total 30-yr average rainfall divided by four (weeks) minus actual precipitation within a given week. Therefore each irrigation amount was calculated and applied according to the rainfall deficit from previous week. Thus, in 2012 and 2013 the Stillwater site received a total of 280 mm and 43 mm of water, respectively.

Flowering time was recorded for both MGs when at least half of the plants in each plot reached the R1 growth stage (Fehr and Caviness, 1977). Canopy cover estimation was done through digital photographs using a method similar to that described by Purcell (2000). This procedure was performed at Stillwater site in 2012 and 2013 and at Perkins site in 2013. Images were taken from 1 m above the soil surface and the camera was mounted on a monopod attached to a piece of PVC pipe with the camera lens pointing down covering approximately 1 m^2. Digital photographs were analyzed using Sigma Scan Pro (v. 5.0, systat software, Point Richmond, CA), which selects the green pixels in the digital image and divides them by the total number of pixels in the image photo, providing a percentage indicating the total percent cover of the plants in the 1 m^2 (Purcell, 2000). Pictures were taken at the R1 growth stage in plots with the determinate cultivar AG 5632, while pictures were taken at the R5 in plots with the indeterminate cultivar REV 48R22, when vegetative growth had ceased (Sinclair, 1984).

To determine seed yield, the whole plots were harvested using a Wintersteiger Delta plot combine (Wintersteiger Inc., Salt Lake City, UT) when plants reached maturity. The combine simultaneously recorded seed yield, seed moisture and test weight of each plot. Seeds were also collected for laboratory measures of moisture and plot weight and yield was adjusted to 130 g kg^{-1} moisture content. Seed yield and maximum percent canopy cover data were analyzed using SAS software version 9.3 (SAS, 2008). Analyses of variance (ANOVA) were performed separately for each site-year using the SAS GLIMMIX procedure to determine differences in seed yield by maturity group, row spacing, and seeding rate and also their interaction. Least significant differences (LSDs) were determined at the 0.05 significance level.

A simple economic analysis was performed to calculate the partial economic return for each treatment so that the optimum plant population could be determined. Plant population density was measured when plants reached R1 by counting all plants in the two inner rows of each plot. Economic analysis was based on the following equation:

$$PER = (\text{Soybean price x Yield}) - (\text{Seed cost}) \qquad \text{Eq. 1}$$

where PER is the partial economic return ha^{-1}, ‘Soybean price’ is the commodity price kg^{-1}, ‘Yield’ is the seed yield measured in kg ha^{-1} and ‘Seed cost’ is measured as the seed price kg^{-1} x seeding rate ha^{-1}. Soybean commodity price was based on average market price at the Chicago Board of Trade and seed costs based on USDA-NASS estimates. Analysis of variance was also used to determine differences in partial economic return among treatments.

2.3. RESULTS AND DISCUSSION

2.3.1. Seed Yield Response

Soybean seed yields were relatively low across all 5 site-years due to low rainfall and warmer average air temperatures during the growing season, compared to common averages for the Southern Great Plains (Table 2). Yield differences were observed among site-years ($P \leq 0.0001$); thus, each site-year was analyzed individually. Seed yield showed no response to either seeding rate or its interaction with the other main effects, regardless of site-year (Table 3). Analysis of variance was conducted using relative yield values, in which soybean seed yield was expressed as a fraction of the average yield across seeding rates for each row spacing in relation to the average yield across all site-years within given MG..

Field experiments during the first two years of study (2011 and 2012) were severely impacted by extreme drought and heat, regardless of location. Very hot and dry conditions during plant establishment (early July), resulted in crop failure at Stillwater and Lahoma sites to fail in 2011 and 2012, respectively. Cumulative rainfall deficits of 84 mm and 62 mm from the 30-yr average during June and July, respectively, significantly impaired plant establishment in Haskell 2011, but the location was salvageable. Consequently, seed yield was reduced across treatments and average yield was 680 kg ha^{-1}, with no yield differences among treatments (Table 3 and Fig. 1).

In 2012, yield results were collected only from the Stillwater site, where supplemental irrigation allowed soybean productivity and yield to be similar to long term averages. At this site-year, differences in seed yield resulted from the fixed effects of

MGs ($P < 0.01$) and row spacing ($P \leq 0.05$) (Fig. 1), but their interaction was not significant ($P = 0.21$). Maturity group 4.8 had lower yields (625 kg ha^{-1}) compared to MG 5.6 (915 kg ha^{-1}) mainly due to flower abortion, since indeterminate cultivar *REV48R22* (MG 4.8) was exposed to extremely hot temperatures for approximately 50 consecutive days from late August through September, while flowering. On the other hand, flowering of the determinate cultivar *AG5605* (MG 5.6) occurred around August 13th, when favorable temperatures for pod formation around 24°C and timely rainfall of approximately 63 mm occurred within few days of flowering. Still at Stillwater 2012, MG 5.6 soybean at 38 cm row spacing resulted in greater yields than 76 cm ($P = 0.02$), but did not differ from 19 cm row spacing ($P = 0.09$), which also did not differ from 76 cm row spacing ($P = 0.55$). There were no yield differences among treatments for MG 4.8.

Weather conditions in 2013 were more favorable for soybean production than the previous two years in the Southern Great Plains, especially during vegetative development. However, the erratic rainfall pattern observed during pod formation and seed filling restricted yield where supplementary irrigation was not provided. At Haskell and Perkins, MG and RS significantly influenced seed yield, whereas in Stillwater 2013 their interaction affected yield (Table 3). In Haskell, seed yield of MG 4.8 was approximately 100 kg ha^{-1} greater than yield of MG 5.6 (Fig. 2). Seed yield of 38 and 76 cm row spacing were similar, but both also had approximately 100 kg ha^{-1} greater yield than 19 cm row spacing. At Stillwater 2013, MG 4.8 had greater yields than MG 5.6 (1600 vs. 1350 kg ka^{-1}) across row spacings. Within MG, 38 and 76 cm row spacings produced statistically equivalent grain yield, and both produced approximately 20% and

18% greater yields than 19 cm row spacing for MG 4.8 and 5.6, respectively. At Perkins 2013, MG 4.8 resulted in 165 kg ha^{-1} greater yield than MG 5.6 and this difference was significant ($P \leq 0.01$). Row spacing also affected yield, and plants sown in 76 cm rows produced greater yield than plants at 19 cm ($P = 0.02$). The 76 and 38 cm row spacing produced similar yield ($P = 0.26$) as did the 19 and 38 cm row spacing ($P = 0.22$). Relative yield comparison within MG 4.8 reveled that only Stillwater 2013 had yields greater than the average yield across site-years, due to more favorable environmental conditions than the other site-years. For MG 5.6, Stillwater 2012 and 2013 had seed production above average across site-years.

The lack of seed yield response to different seeding rates is fairly common for soybean (Lee et al., 2008). Some authors have recorded greater seeding rate being required under dry environmental conditions than wet environments (Holshouser and Whittaker, 2002) or when planted late (Holshouser and Jones, 2003). However, congruent with our findings, Devlin et al. (1995) concluded that under limited soil moisture conditions, yield was not affected by increasing seeding rates. In four out of five site-years MG affected seed yield (Fig. 2), but this response varied when weather conditions were different among site-years at flowering and pod filling periods. Our findings regarding row spacing were again similar to Devlin et al. (1995), which reported that under limited soil moisture availability, seed yield was greater at wide row spacing than narrow rows. Alessi and Power (1982) also reported that under water deficit stress conditions, soybean planted in narrow rows had lower water-use efficiency. In a similar study conducted in Iowa, Taylor (1980) demonstrated that during dry growing seasons, no seed yield differences were found between 25, 50, 75, and 100-cm row spacing.

Overall, low seed yield response to narrow row spacing and increased seeding rates, for both MGs, are due a combination of late plantings and non-optimal weather conditions, masking any effect that row spacing or seeding rate might have in a well-watered system. Although the two wider row spacings resulted in higher yields than narrow rows, these yields are still lower than optimal. Average yield, across all site-year was 937 kg ha^{-1}, which is 45% of the State record average yield of 2085 kg ha^{-1} (NASS-USDA, 2014).

2.3.2. Plant Population

Plant population averaged about 70% of seeding rates at Haskell and Stillwater in 2011 and 2012, respectively, and approximately 80% of seeding rate for all 2013 sites with little variation between MGs. Seeding rates of 198,000, 260,000, 321,000, and 383,000 seeds ha^{-1} produced a final population of about 153,000, 204,000, 247,000, and 298,000 plants ha^{-1} across site-years. Analysis of variance for each site-year showed that final plant population did not affect seed yield (P=0.14). In other words, soybean treatments at low final plant populations yielded as much as treatments at high plant populations, regardless of site-year, MG, or row spacing.

As stated before, the lack of yield response to plant population found in this study agrees with other studies. Lee et al. (2008) and Popp et al. (2006) stated that soybean plants can yield similarly in a wide range of seeding rates, and also that yield response to plant population depend on specific combinations of seeding rate, MG, and environmental conditions. Lehman and Lambert (1960) and Basnet et al. (1974) also reported that yield response to plant population is normally small and inconsistent. Under limited soil moisture, difference in yield may only appear at larger range of populations than what were used in this study. A study under dry soil conditions in Virginia required approximately three-fold increase in plant population for maximum yield compared to when soil moisture was not limited (Holshouser and Whittaker, 2002). In the present study, plant population did not affect seed yield possibly because of the narrow range of seeding rates.

2.3.3. Canopy Cover

From the three site-years where canopy pictures were taken, Stillwater in 2012 and 2013 had differences in percent soybean canopy cover at maximum vegetative growth as a function of row spacing (P < 0.0001 for both) (Fig. 3). At in Perkins 2013, maximum canopy cover was not influenced by row spacing (P = 0.39). Maturity group and seeding rate were not different within a location, so percent canopy cover values were averaged across MGs and seeding rates. Overall, percent canopy cover decreased as row spacing increased (Fig. 3); however, seed yield did not follow the same trend, and had greater yields at the two wider row spacing compared to 19 cm (Fig 1). This is most likely due to the greater soil water requirement by plants at narrow row spacing since they normally have greater transpiration as demonstrated by Hargreaves and Samani (1982) and Edwards et al., (2005). Consequently, seed yield at 19 cm row spacing was likely more impacted by depleted soil moisture than wider row spacings. Similarly, Alessi and Power (1982) also concluded that soybean planted at 19 cm rows used more water than plants at 76 cm rows. Wells (1991) and Kane and Grabau (1992) have reported that greater plant population is required to maximize light interception in late plantings, since soybean plants are generally shorter and with less canopy cover at R1.

Although these results disagree with our findings, both studies were conducted under adequate soil water conditions. Therefore, water deficits were probably the major yield limiting factor in the present study.

2.3.4. Partial Economic Return

Soybean seeds are generally sold in bags of 22.7 kg. For this reason, partial economic return was calculated converting the number of seed ha^{-1} to seed weight ha^{-1}. This total seed weight ha^{-1} depends on individual seed weight, so that seed cost ha^{-1} can be calculated. Since individual seed weight was different between MG 4.8 and 5.6 with 14.8 and 16.5 g (100 seeds^{-1}), respectively, analysis of variance to compare partial economic return was performed within MG. Also, considering that partial return is relative to seed yield, these statistical analyses were performed across site-years to summarize results. Therefore, return was calculated as a function of seeding density and row spacing within MG and across site-years. Following the same trend of seed yield, partial economic return of 38 and 76 cm row spacings were statistically equivalent but both had approximately 25, 26, 20, and 13% greater returns than 19 cm rows, for 198,000, 260,000, 321,000, and 383,000 seeds ha^{-1}, respectively, regardless of MG (Fig. 4). Greatest partial return was obtained from soybean planted in 38 cm rows at the lowest seeding rate (198,000 seeds ha^{-1}) with US$ 459 for MG 4.8 and US$ 434 for MG 5.6. For both MGs, returns from 19 cm row spacings were similar across seeding densities, while returns from 38 and 76 cm rows tended to decrease as seeding density increased (Fig. 4). These lower returns at higher seeding densities are explained by the increased seed costs. Research conducted in Arkansas by Edwards et al. (2005) reported similar results, in which the economic return reduction was calculated for each additional plant, varying according to seed cost. In another study conducted in Kentucky, Lee et al. (2008) observed that economically optimum plant populations were 7 to 33% less than optimal plant populations for the greatest seed yield. Most of the partial economic return relies on seed cost and seed yield; thus, if seed yield was not affected by seeding rate in this experiment, greater economic returns were obtained at lower seeding rates or final plant population in which seed costs would be reduced.

2.4. CONCLUSION

In this study, seed yield was low regardless of row spacing, seeding rate, or maturity group studied. Average yield, across all site-years was 45% of the state record average yield (2085 kg ha^{-1}) (NASS-USDA, 2014). Factors such as late planting, scarce rainfall, and above normal temperatures during growing seasons, prevented soybean from achieving its full yield potential. Maturity group affected yield but the response varied according to weather conditions during flowering periods. Row spacing affected soybean seed yield in most site-years; however no differences in yield between 38 and 76 cm row spacing were observed, except at Stillwater in 2012, where yield was greater at 38 cm versus 76 cm rows. In general, 38 and 76 cm row spacings yielded either greater or similarly to 19 cm rows, showing slight advantage to 19 cm rows in the southern Plains. Seeding rates and consequently final plant populations had no effect on seed yield. Therefore, under low-yielding environments around the Southern Great Plains, seeding rates could be as little as 198000 seed ha^{-1}. Higher seeding rates may protect against poor emergence and/or other yield reducing factors post-emergence and still be justified as a form of insurance against poor emergence (Popp et al., 2006). As expected, canopy cover at maximum vegetative growth was greater at 19 cm row spacing compared to 38 and 76 cm; however, it did not translate in greater seed yield, possibly due to the lack of soil moisture to fulfill increased water requirements at greater light interception and transpiration. Similar to seed yield, partial economic return was affected by row spacing where returns of 38 and 76 cm rows ranged from 13 to 25% greater than 19 cm row spacing, with the greatest differences at the lowest seeding densities. Across site-years, partial economic return reduced as seeding rate increased, regardless of MG. Most of the partial economic return relies on seed cost and seed yield; therefore, since seed yield was similar across seeding rates, greater partial profitability was obtained at lower seeding rates, where seed costs were diminished. Results from this study suggest that, under late-planting and water-limited environments, soybean seed yield results tend to be low regardless of management practices. However, to minimize yield reduction in this scenario, soybean should be planted at wide row spacing, and low seeding rate (198,000 seeds ha^{-1}). In this manner seed yield may be either greater or similar to the other treatments and partial economic return increased by reducing seed costs,

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Table 1. Planting dates by location and year for soybean MG, seeding density, and row spacing studies conducted in Oklahoma.

Year	Location	Planting Date
2011	Stillwater, OK	04 July
	Haskell, OK	05 July
2012	Stillwater, OK	03 July
	Lahoma, OK	04 July
2013	Stillwater, OK	26 June
	Haskell, OK	27 June
	Perkins, OK	28 June

Table 2. Rainfall and air temperature (Tmean) data recorded at the four experimental locations during 2011 to 2013. Deviations from 30-yr average reported in parentheses.

		June		July		August		September		October	
Year	Location	Tmean	Rainfall	Tmeam	Rainfall	Tmean	Rainfall	Tmean	Rainfall	Tmean	Rainfall
		^{o}C	mm	^{o}C	mm	^{o}C	mm	^{o}C	mm	^{o}C	mm
2011	Stillwater	28.7 (-4.1)†	43 (-66)	32.4 (4.8)	19 (-50)	30.9 (3.8)	48 (-30)	21.2 (-1.2)	62 (-43)	16.5 (0.4)	18 (-65)
	Haskell	27.6 (2.9)	26 (-84)	31.1 (3.5)	7 (-62)	30.0 (2.9)	119 (41)	20.6 (-1.8)	92 (-13)	16.5 (0.4)	48 (-35)
2012	Stillwater	25.9 (1.2)	55 (-55)	30.7 (3.1)	2 (-67)	28.0 (0.9)	67 (-10)	23.6 (1.3)	28 (-77)	15.4 (-0.7)	15 (-67)
	Lahoma	26.1 (0.5)	59 (-52)	30.9 (2.4)	10 (-60)	27.0 (-0.7)	47 (-38)	22.9 (-0.3)	2 (-78)	15.0 (-1.8)	2 (-83)
2013	Stillwater	25.5 (0.8)	100 (-9)	26.5 (-1.1)	138 (69)	26.8 (-0.4)	65 (-13)	24.0 (1.6)	43 (-62)	15.5 (-0.6)	56 (-27)
	Haskell	25.5 (0.8)	105 (-5)	26.4 (-1.2)	154 (86)	26.9 (-0.2)	121 (44)	24.3 (1.9)	49 (-56)	16.1 (0.1)	96 (13)
	Perkins	24.8 (-0.1)	112 (0)	25.9 (-2.0)	112 (45)	25.7 (-1.6)	85 (15)	23.5 (0.9)	60 (-46)	15.5 (-0.9)	56 (-29)

† Deviations were calculated by subtracting 30-yr averages from actual recorded values.

Table 3. Significance of *F* values from analysis of variance of seed yield within each site-year.

Source of variation	Seed yield comparisons				
	2011	2012	2013		
	Haskell	Stillwater	Haskell	Stillwater	Perkins
Maturity Group (MG)	NS†	***	***	***	**
Row spacing (RS)	NS	*	*	***	*
MG x RS	NS	NS	NS	***	NS
Seeding rate (SR)	NS	NS	NS	NS	NS
MG x SR	NS	NS	NS	NS	NS
RS x SR	NS	NS	NS	NS	NS
MG x RS x SR	NS	NS	NS	NS	NS

* Indicates significance at $P \leq 0.05$.

** Indicates significance at $P \leq 0.01$.

*** Indicates significance at $P \leq 0.0001$.

† NS, not significant at 0.05 probability level.

Table 4. Significance of *F* values from analysis of variance of partial economic return within each site-year.

Source of variation	Seed yield comparisons 2011 Haskell	2012 Stillwater	2013 Haskell	2013 Stillwater	2013 Perkins
Maturity Group (MG)	NS†	***	***	***	**
Row spacing (RS)	NS	*	**	***	NS
MG x RS	NS	NS	NS	***	NS
Seeding rate (SR)	NS	NS	***	NS	NS
MG x SR	NS	NS	NS	NS	NS
RS x SR	NS	NS	NS	NS	NS
MG x RS x SR	NS	NS	NS	NS	NS

* Indicates significance at $P \leq 0.05$.

** Indicates significance at $P \leq 0.01$.

*** Indicates significance at $P \leq 0.0001$.

† NS, not significant at 0.05 probability level.

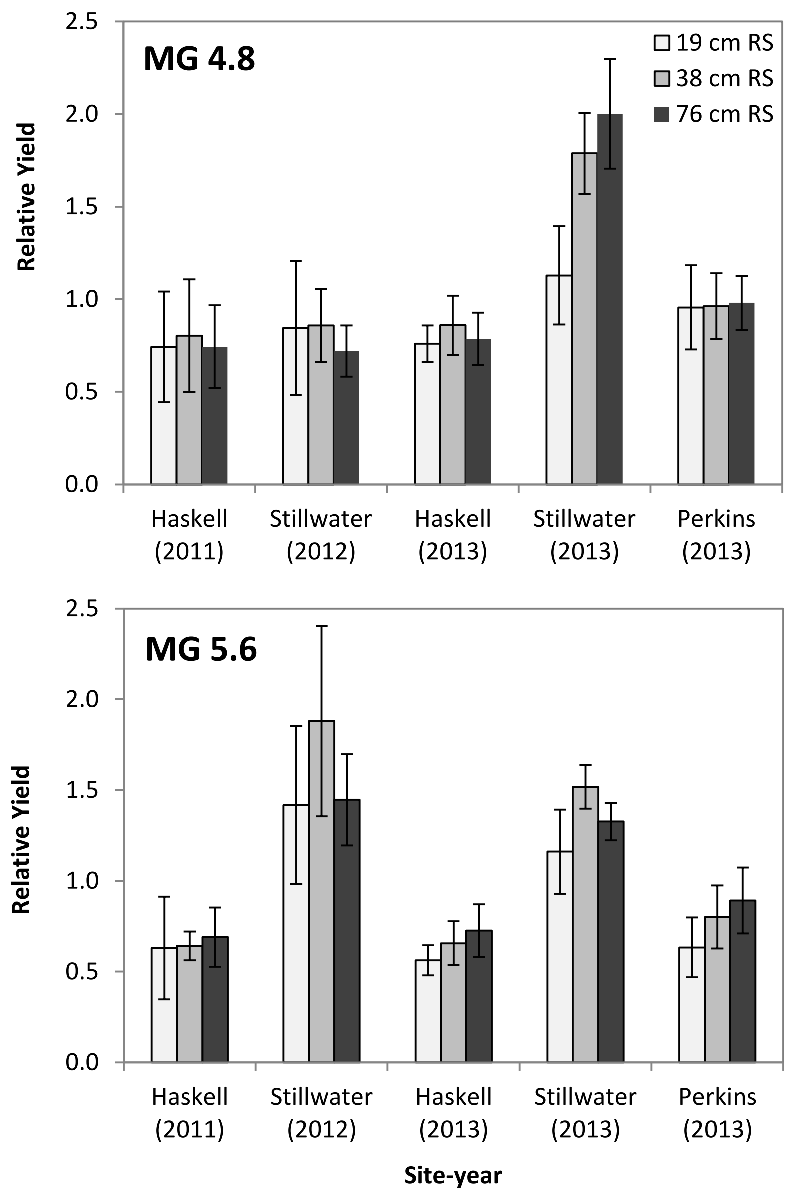

Figure 1. Soybean relative yield as affected by row spacing within MG 4.8 (A) and 5.6 (B) at sites in Oklahoma. Relative yield was determined dividing the average yield across seeding rates for each row spacing by the average yield across all site-years within given MG. Error bars indicate the standard deviation across seeding rate for each row spacing within site-year.

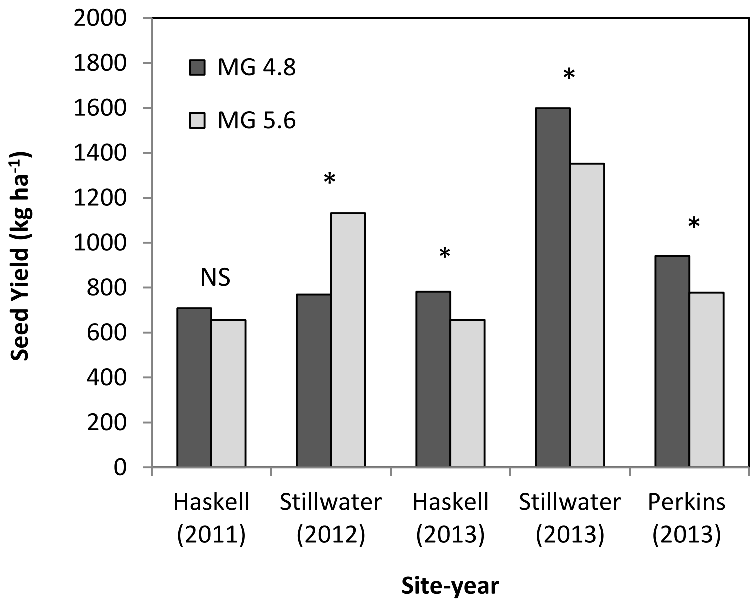

Figure 2. Soybean seed yield averaged across row spacing and seeding rate for each site-year and MG within site-year. * Indicates significance at *P* ≤ 0.05, and "NS" not significant at 0.05 probability level.

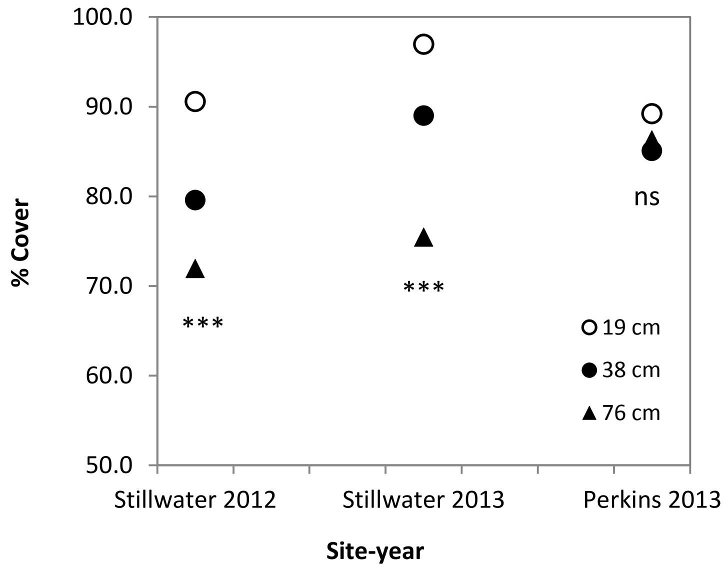

Figure 3. Percentage soybean canopy cover at maximum vegetative growth by row spacing across maturity groups 4.8 and 5.6 at Stillwater site in 2012 and 2013 and Perkins in 2013. * Indicates significance at *P* ≤ 0.0001, and "NS" not significant at 0.05 probability level.**

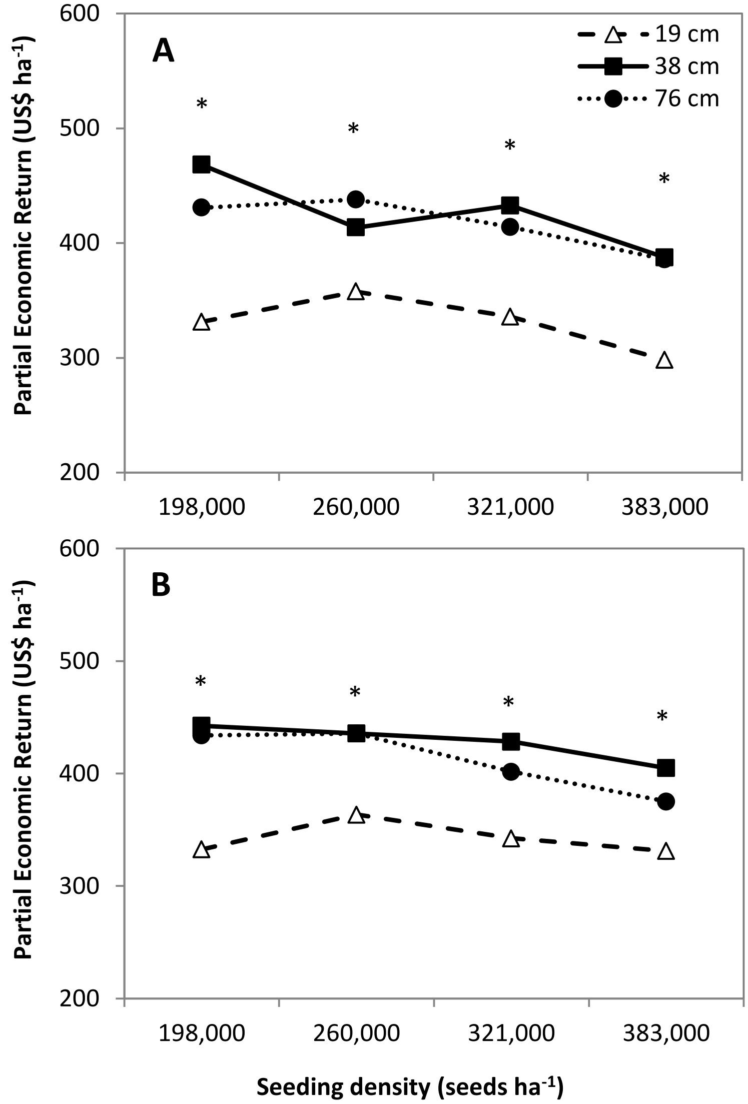

Figure 4. Partial economic return of (A) MG 4.8 and (B) MG 5.6 soybean as a function of seeding density across site-year for each row spacing. * Indicates significance at *P* ≤ 0.05 at the 0.05 probability level. Partial economic return of MG 4.8 and 5.6 cultivar for each row spacing and seeding rate within site-year in displayed in Table A-5 and A-6 of the appendices section.

CHAPTER III

EXPLOITING THE USE OF LONG JUVENILE SOYBEAN AS A STRATEGY TO REDUCE YIELD LOSS OF LATE PLANTINGS IN THE SOUTHERN GREAT PLAINS

3.1. INTRODUCTION

Soybean is a short-day plant, which means that flowering is induced when night length exceeds a critical minimum. As such, the time to soybean flowering can vary as day-length changes. (Garner and Allard, 1920). During the summer in the United States, days are shorter in low latitudes regions (i.e. southern U.S.). Therefore, soybean sown in these regions will flower sooner than when sown under northern latitudes at same day, shortening vegetative development and consequently compromising yields. Prior to mid-70`s, geographical adaptation of non LJ soybean production was limited to latitudes above 22$^{o}$, and the primary restrictive factor was photoperiod (Scott and Aldrich, 1983). This barrier was overcome in the late 70`s with the introduction of a delayed flowering trait in soybean plants (Neumaier and James, 1993). This trait was identified in lines PI 159925 and ‘Santa Rosa’ by Hartwig and Kiihl (1979) and required about 60 d from emergence until flower as compared to 30 d in common species. This characteristic was later called “long juvenile” (LJ) to describe delayed flowering. Although the genetic control of the LJ trait is not completely understood (Cober, 2011), the effect of this trait in delaying flowering on soybean has been well documented (Board and Hall. 1984; Cregan and Hartwig, 1984; Board, 1985; Parvez and Gardner, 1987; Sinclair and Hison, 1992; Wilkerson et al., 1989; Tomkins and Shipe 1997). A study conducted at Blackville and Pendleton, SC, by Tomkins and Shipe (1997) reported that LJ genotypes were similar in yield to MG 7 and 8 across different planting dates, but when compared to MG IV, LJ yield was greater by 56% at early planting dates.

In the northern hemisphere, after 21 June daylenght starts to decrease. In the southern U.S., since days are inherently shorter than in the northern U.S., late-planted soybean (after mid-June) tends to flower with insufficient biomass and vegetative growth compared to early-plantings (mid-Apr – early June) (Barreiro and Godsey, 2013). Producers in the southern US, including Oklahoma, often choose a double-cropping system to increase profitability, system in which soybean is planted after winter wheat harvest. Double crop soybean system regularly leads to delayed soybean planting dates and less time to complete the growing cycle. (Egli and Bruening, 2000). Double-crop soybean generally has reduced grain yield as compared to fall season (Egli and Bruening, 2000; Wesley, 1999). Along with reduced biomass due to photoperiod, poor yield may also be related to frost (Purcell et al., 2002), and to lower soil moisture availability (Egli and Bruening, 2000; Godsey, 2011; Knapp et al., 1980; Purcell et al., 2003).

Given the lack of data regarding LJ trait soybean cultivars in the Southern Great Plains of the U.S. and the characteristics previously discussed, we hypothesize that soybean MGs 6, 7, and 8, carrying the LJ trait, will have increased growth and yield performance as compared to MG without the LJ trait. Thus, the objectives of this study were to evaluate leaf area, canopy closure, seed yield, and seed protein and oil concentration of LJ lines compared to non LJ cultivars, when planted late in the season.

3.2 MATERIAL AND METHODS

Three site-years were included in this study: Stillwater, OK (2012 and 2013) and Perkins, OK (2013). In Stillwater the trial was established on an Easpur loam (fine loamy, mixed, superactive, thermic Fluventic Haplustolls) located at the Oklahoma State University Agronomy Research Station in Stillwater, OK (36°07’28.52” N, 97°06’12.93” W, elevation 266 m). In Perkins, the trial was conducted on a Teller loam (fine-loamy, mixed, active, thermic Udic Argiustolls) located at the Cimarron Valley Research Station in Perkins, OK (35°59’16.68” N, 97°02’46.28” W, elevation 279 m). The experimental arrangement was a split-block design with three replications. Whole plots were planting dates and sub plots were soybean MGs ranging from 3.8 to 8. The first two planting dates periods (i.e. late-May and early-June) were considered full-season plantings, and the last two planting dates (mid-June and late-June) were considered late planting date for Oklahoma. Planting dates were approximately 10 days apart from each other. Three soybean cultivars were high yielding glyphosate resistant soybean cultivars from MGs 3.8, 4.7, and 5.6, selected based on previous yield performance studies (Barreiro and Godsey, 2013). The other three were LJ near-isoline pairs: SC-1850, SC-1930, and SC-7020 from MG 6, 7, and 8. Plot size was 3 m wide by 7.6 m long. Seeding rate was 333,000 seeds ha^{-1} sown 2.5 cm deep in 76 cm row spacing using a Monosem vacuum planter (Monosem, Inc. Edwardsville, KS). Prior to planting, soybean seeds were inoculated with *Bradyrhisobium japonicum* (EMD BioScience, Brookfield, WI).

Soil samples were taken from all site-years (Table 1). No supplemental soil fertilization was required at any of the sites according to Oklahoma State University Cooperative Extension recommendations (Pratt et al., 2009). Weed and pest management practices were also conducted according to Oklahoma State University Cooperative Extension recommended practices (Pratt et al., 2009). At all site-years, weeds were controlled with 2.2 kg ha^{-1} metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] and 0.8 kg ha^{-1} pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] pre plant followed by 0.07 kg ha^{-1} quizalofop-P-ethyl mixed with 0.43 kg ha-1 kg ha^{-1} acifluorfen 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid post-emergence. Insect control was necessary only at the Stillwater site in and consisted of 0.13 kg ha^{-1} methoxyfenozide 3,5-Dimethylbenzoic acid N-tert-butyl-N-(3-methoxy-2-methylbenzoyl)hydrazide to suppress soybean looper (*Pseudoplusia includes*) infestation in 2012 and 0.028 kg ha^{-1} lambda-cyhalothrin* to suppress green cloverworm (*Hypena scabra)* infestation in 2013.

Long-juvenile near-isoline pairs SC-1850 (MG 6), SC-1930 (MG 7), and SC-7020 (MG 8) were obtained from Dr. Emerson Shipe (Clemson Univ.) and were tested to be compared in yield potential to high yielding non LJ cultivars adapted to the Southern Great Plains. Supplemental irrigation was provided at Stillwater in both years to guarantee plant establishment and development throughout the summer. Sprinkler irrigation was managed from planting through R7 stage (Fehr and Caviness, 1977) with two applications per week, accounting for approximately 12.5 mm of water per application (100 mm mo^{-1}). This irrigation frequency and amount was used to reflect soybean crop water requirements (average evapotranspiration during growing season), considering the 30-yr average rainfall and soil water holding capacity at soybean effective root zone. No irrigation was available at Perkins site. Thirty-year average rainfall and air temperature for Perkins are shown in Figure 1.

To estimate soybean vegetative growth, plant height and canopy cover measurements were taken. Plant height was recorded by measuring the length of main stem at the R5 stage when vegetative growth had ceased (Sinclair, 1984). Percent canopy coverage was estimated through digital photographs of approximately 1 m^2 from each plot using a method similar to that described by Purcell (2000). Pictures were taken on a weekly basis from 1 m above the soil surface and the camera was mounted on a monopod attached to a piece of PVC pipe with the camera lens pointing down. Digital photographs were analyzed using Sigma Scan Pro (v. 5.0, systat software, Point Richmond, CA), which selects the green pixels in the digital image and divides them by the total number of pixels in the image, providing a percentage indicating the total percent green coverage in the 1 m^2 (Purcell, 2000). Thermal units (*Tu*) were calculated using the following equation:

$$Tu = \left[\frac{(T_{MAX} + T_{MIN})}{2}\right] - T_{BASE}$$

where T_{MAX} is the daily maximum air temperature, T_{MIN} is the daily minimum air temperature, and T_{BASE} is the temperature below which the plant do not progress in growth (McMaster and Wilhelm, 1997). The base temperature for soybean is 10°C (Brown, 1960). Daily T_{MAX} and T_{MIN} for each location were obtained from the Oklahoma Mesonet website (http://agweather.mesonet.org/). For each site-year and planting date, fractional coverage (dependent variable) and *Tu* (independent variable) were plotted to estimate maximum canopy cover for each MG.

Seed yield was determined by harvesting the center two rows of each plot using a Wintersteiger Delta plot combine (Wintersteiger Inc., Salt Lake City, UT) when plants reached maturity. Seeds were also collected for laboratory measures of moisture and plot weight and yield was adjusted to 130 g kg^{-1} moisture content. Seed protein and oil concentration were measured using a near-infrared (NIR) spectroscopy model Perten DA7200 (Perten Instruments Inc., Springfield, IL). This NIR technique uses the sum of absorbances at different wavelengths (Batten, 1998).

Statistical analyses were performed using SAS software version 9.3 (SAS Institute, Cary, NC). Analyses of variance (ANOVA) were performed using the GLIMMIX procedure of SAS to determine differences in total days from planting to R1 and R8 developmental stages (Fehr and Cavinness, 1977), plant height, and maximum canopy cover, along with seed yield, oil, and protein concentrations among MG within and across planting date. Least significant differences (LSDs) were determined at 0.05 significance level.

3.3 RESULTS

3.3.1 Vegetative Growth and Maturity Response to LJ Trait

Dates for the R1 and R8 stages were recorded from all plots; however plants from the same MG flowered or matured on the same day within given planting date; therefore, there were no formal replications for number of days after planting (DAP) to R1 and R8 developmental stage. For this reason, the three site-years were combined and average DAP to R1 (vegetative growth period) and to R8 (maturity period) was determined for each MG by planting date (Figure 2). There were slightly differences in planting date among sites, so planting dates are expressed as late-May, early-June, mid-June, and late-June planting date. As expected all three LJ lines (MG 6, 7, and 8) had longer growth and maturity periods as compared to MG 3.8, 4.7, and 5.6 cultivars, regardless of planting date (Figure 2). Similar results were reported by several investigators such as Board and Settimi (1986), Tomkins and Shipe (1997) and Cober (2011). No planting date x MG interaction was observed ($P = 0.45$). Across all MGs, the vegetative growth period (days to R1) was reduced only in the late-June planting date and was reduced by approximately 8 d compared to the first three planting dates (Figure 2). Significant differences were observed in DAP to R1 ($P < 0.0001$) among MG at all four planting dates, and DAP to R1 increased as MG increased. Therefore, MG 3.8 reached the flowering period earliest, with an average of 40 d for the first three planting dates and 32 d for the last planting date. Maturity group 8 (LJ), which took the longest time to reach R1, had an average of 70 d for the first three planting dates and 60 d for the last planting date (Figure 2). Regarding the time to soybean plants reach maturity (R8 stage), both planting date and MG affected DAP to R8 ($P < 0.0001$), but no planting date x MG interaction was observed (P = 0.62). All six MG had their longest time to R8 at the first planting date (late-May) and this period reduced as planting date was delayed. This reduction in DAP to R8 was approximately 7 d from one planting date to the next across all MGs. Similarly to DAP to R1, DAP to R8 significantly increased as MG increased regardless of planting date (Figure 2). Therefore, the LJ trait resulted in longer vegetative period and longer days to maturity than any of the studied non LJ cultivars for every planting date.

3.3.2. Plant Height and Maximum Canopy Cover

At Stillwater 2012, plant height (main stem length) of LJ lines was not different across planting dates; however, at Stillwater 2013 LJ lines sown at the first planting date (May 24) produced plants approximately 17 cm taller than the other three planting dates (Table 2). At Stillwater 2012 and 2013, non LJ cultivars planted at the first two planting dates resulted in similar heights and were approximately 21 cm taller than when they were planted in the last two planting date (Table 2). Although mid-June or late-June planting dates resulted in similar plant heights for most of the non LJ cultivars at Stillwater 2012 and 2013; delaying planting date for MG 3.8 to 27-June resulted in further decrease in plant height in Stillwater 2013. At Perkins 2013, differences in plant height comparing LJ lines were not significant across planting dates, except for LJ MG 6 which was lower plant height at the first planting date. Non LJ cultivars from second (04-Jun) and last (27-Jun) planting date had the highest and shortest plants, respectively, across planting dates (Table 2). Different from Stillwater site-years, lower plant heights of non LJ cultivars and LJ MG 6 was due to the poor plant establishment caused by crusted soil after planting, then, plants at low population had greater branching instead growing in height (Carpenter and Board, 1997).

When comparing LJ lines (MG 6, 7, and 8) to non LJ cultivars (MG 3.8, 4.7, and 5.6), similar heights were observed at the first two planting dates, except to LJ MG 8 which had taller plants than non LJ cultivars at first planting date of all three site-years. When planting was delayed, LJ lines were taller than non LJ cultivar at the last two planting dates at Stillwater 2012 and 2013, and at last the planting date at Perkins 2013. Overall, non LJ soybean cultivars tended to decrease in height as planting date was delayed, while LJ plants were similar in height regardless of planting date. The increased plant height in LJ lines observed in late planting dates is an important indicator of greater vegetative growth by these lines that may favor soybean yield when being late-planted.

Soybean vegetative growth rate (cumulative thermal units (*Tu*) until plants reach maximum canopy cover) was not different across planting dates or MG; thus, only maximum canopy cover of each MG and planting date within site-year will be discussed (Table 3). At Stillwater 2012, there was no difference in maximum canopy cover among planting dates ($P = 0.25$). However, comparisons among MG across all planting dates resulted in lower maximum canopy cover (75 % vs. 85 %, $P < 0.05$) for MG 3.8 when compared to the other MGs (Table 3). An example of these results is also shown in Figure 3 for Stillwater 2012. At Stillwater 2013, differences among planting dates were observed ($P < 0.05$). The first two planting dates resulted in greater maximum canopy cover across MG averaging 90.5 % and canopy cover decreased as planting date was delayed. Planting date of 15-Jun and 27-Jun reached 87 and 83 % maximum canopy cover, averaged across MG. Non LJ cultivars achieved lower maximum canopy cover compared to LJ lines; except MG 5.6 which was similar to LJ MG 6 and 7. At Perkins 2013, although there were no canopy cover measurements from the first planting date, differences were detected among the three planting dates (*P* < 0.05), in which greatest cover was from the second planting date (4-Jun) with 95 % and reduced to 91 and 86 % for 15- and 27-Jun planting dates, respectively. Comparing MGs, greater maximum canopy cover was observed in LJ MG 6 and 7, which both reached 94 % cover, compared to the other MGs. In exception, LJ MG 6 reached similar maximum cover to MG 4.7 and 8 (LJ). Maturity group 3.8 had the lowest canopy cover averaging 85 % at this location.

3.3.3 Seed Yield Response

Seed yield was analyzed separately for each site because Perkins 2013 did not receive irrigation as in Stillwater. In Stillwater 2012, LJ MG 6 had greater seed yield compared to LJ MG 7 at the last two planting dates and greater than LJ MG 8 at all planting dates. At the first two planting dates, MG LJ 6 had similar yield to the non LJ cultivars (MG 3.8, 4.7, and 5.6) (Table 2). Seed yield at the last planting date (25-Jun) was significantly lower compared to the first two planting dates (21-May and 02-Jun), but similar to the third planting date (13-Jun) for all MGs. Within MGs 5.6, 6 (LJ) and 8 (LJ), yield was similar among first, second, and third planting dates. At Stillwater 2013, all three LJ MGs showed no yield difference in the first three planting dates, but seed yield of MG 6 was greater than MG 7 and 8 at the last planting date (25-Jun). At the first planting date (21-May) all three LJ soybean lines produced greater yield than MG 3.8, 4.7, and 5.6 cultivars. However, for the last three planting dates, MG 4.7 cultivar had slightly greater seed yield than the other MGs except LJ MG 6 and 7. At this site-year, planting date had no effect on seed yield. Long-juvenile lines had greater yield at first and third planting dates as compared to the second and last planting date (Table 2). The seed yield range at Perkins 2013 was lower than the Stillwater site-years, mainly because irrigation was not provided. The first planting date (27-May) at this location resulted in no yield differences among MG. At the second planting date (4-Jun), MG 3.8 and 4.7 had lower yield only when compared with LJ MG 8 line. Maturity group 5.6 did not differ in seed yield compared to LJ lines. At the 15-Jun and 27-Jun planting dates, LJ MG 6 and 7, respectively, had greater yield only when compared to MG 3.8, but similar to the others that were also similar in yield to MG 3.8 in both planting dates. No yield differences were observed comparing planting dates within each MG. Least squared mean yield for each MG and comparisons among them within and across planting dates for each site-year are shown in Table 2. Increased vegetative period and growth but similar seed yield of LJ lines versus non LJ cultivars can be interpreted as lower harvest index by these LJ lines. The harvest index is defined as the fraction of seed production in relation to the total above ground dry matter production. Research conducted in Iowa by Shibles and Weber (1966) reported that the extended period for vegetative growth overlaps reproductive phase creating a competition within the plant for available photoassimilates, which results in less carbohydrate available for seed production.

3.3.4 Seed Protein and Oil Concentrations

Soybean seed protein concentration was not influenced by planting date at Stillwater 2012 or 2013 ($P = 0.06$ and $P = 0.18$, respectively) or in Perkins 2013 ($P = 0.46$), but differed by MG at all three site-years. Therefore, protein concentration mean comparisons for MG were averaged across planting dates (Table 4). At all site-years, little variability in seed protein concentration was observed among treatments, which led to small differences being statistically significant, even though the differences might not be of practical significance. At Stillwater 2012, protein concentration across planting dates varied approximately 1.5 % from MG 8 (34.8 % protein) to MG 5.6 (33.3 % protein). Maturity group 5.6 did not differ from MG 4.7, but was lower than MG 3.8, 6 (LJ), and 7 (LJ). At Stillwater 2013, all LJ soybean lines were similar in seed protein concentration but were in average greater by 1.6 % than non LJ cultivars. For Perkins 2013, LJ MGs 6 and 7 had similar seed protein concentrations, but greater than all other MGs. Overall, at all site-years protein concentration of LJ MGs was either greater or similar to non LJ cultivars of lower MGs. This increased seed protein concentration in longer season cultivars found in our study was also described by Gbikpi and Crookston (1981). Concerning seed oil concentration, only individual MG was affected oil concentration, regardless of site-years; thus MG comparisons were performed using averaged means across planting dates. At all three site-years, MG with LJ trait had similar seed oil concentrations; however, these amounts were 1.7, 1.9, and 1.5 % lower than in non LJ cultivars for Stillwater 2012 and 2013 and Perkins 2013, respectively. No difference in oil concentration was observed among MG 3.8, 4.7, and 5.6 (Table 4).

3.4. DISCUSSION

The LJ trait consistently extended vegetative growth of MG 6, 7, and 8 at each planting date compared to the non LJ cultivars. This response in delaying flowering by LJ trait agrees with studies by Board and Hall (1984); Sinclair and Hison (1992); and Tomkins and Shipe (1997). Contrasting individual MG across planting dates, a similar growth period was observed for planting dates from late-May until mid-June but significantly decreased at the late-June planting date. Time to maturity was delayed as MG increased at all planting dates and DAP to R8 reduced approximately 7 d for every 10 d of delayed planting. Since the average date of first freezing event for Stillwater and Perkins is 27-Oct (http://climate.ok.org/), LJ lines from MG 7 and 8, when planted in mid- or late-June, can potentially be at R6 or R7 stage at this date. Possible occurrence of freezing events at these stages can cause frost injury on plant structures in which seed filling processes may be compromised and consequently reduce seed yield (Saliba et al., 1982).

The extended period of vegetative growth for the LJ lines observed in all three site-years, positively reflected in some morphological characteristics such as plant height and canopy cover compared to the non LJ cultivars, especially at later planting dates. Long juvenile lines had similar height at the first two planting dates compared to the non LJ cultivars with average of 67 cm, but were approximately 17 cm taller at the last two planting dates averaging 63 cm. Canopy cover followed the same trend as canopy height with similar maximum cover comparing LJ lines to non LJ cultivars at planting dates prior to mid-June, but greater cover for LJ at mid- and late-June planting dates (89% vs. 81%). In agreement to our results, Tomkins and Shipe (1997) also reported increased accumulated vegetative growth and plant height in response to the LJ trait at late plantings using MG 4, 5, and 6 grown near Pendleton, SC, compared to non LJ cultivars from the same MG. Although morphological characteristics such as plant height and canopy cover were increased in response to the LJ trait, seed yield did not follow the same trend. For all three site-years, similar yield was observed comparing LJ lines vs. non LJ cultivars at planting dates until mid-Jun. Only at the latest planting date (late-June) LJ MG 6 constantly resulted in greater yield when compared to MG 3.8. Also, no yield increment was observed comparing LJ MG 7 and 8 lines to non LJ cultivars at this planting date. Likewise, Tomkins and Shipe (1997) described no seed yield improvement by LJ trait in MG 6 isolines.

Analysis of seed protein and oil concentrations to evaluate the potential advantage of LJ lives over non LJ cultivars generated consistent results over site-years. Seed protein concentration was not affected by planting date, but late MG with LJ trait tended to have greater protein concentrations compared to non LJ cultivars from earlier MGs. Although Gbikpi and Crookston (1981) have tested different MGs than those from the present study, and found similar responses. Conversely, seed oil concentration results revealed lower percentiles at LJ compared to non LJ cultivars regardless of planting date and site-year.

The LJ trait increased vegetative growth which usually has an important role on plant development, solar radiation interception, and seed yield. However, the lack of seed yield increase in response to LJ trait versus non LJ cultivars in this study suggests that excessively extended vegetative period and growth resulted in response to the LJ trait. This physiological characteristic may have diminished seed yield possibly because of insufficient carbohydrates being available for seed production since vegetative period encroaches upon the reproductive phase. Similar results were concluded by Shibles and Weber (1966) in a study conducted in Iowa under extended photoperiods. The authors reported lower seed production in relation to dry matter production (lower harvest index) for soybean varieties that had excessively long vegetative period and greater growth, due to less carbohydrates available for seed growth since it was also being utilized for vegetative growth.

Furthermore, this limited yield performance by LJ lines may also be due to reduced yield components such as number of pods per node and number of seeds per pod although no evaluation of this nature was conducted. These type of assessments would be essential for future studies to quantify these agronomical characteristics at these three LJ lines. Moreover, future studies utilizing earlier MG carrying the LJ trait such as MG 4 and 5, plus breeding programs focused in ameliorate their yield components and their adaptation for late sowings in the Southern Great Plains might increase seed yield performance compared to non LJ cultivars.

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Table 1. Soil pH, OM, and nutrients results from soil samples collected at prior to planting from all experiment sites in 2012 and 2013 in Oklahoma.

Year	Location	pH†	OM	Nutrients		
				NO_3-N‡	P‡	K‡
			%	mg kg^{-1}		
2012	Stillwater	6.2	0.7	8.0	38.0	131.5
2013	Stillwater	6.6	0.7	6.0	39.0	140.5
2013	Perkins	6.0	0.8	4.7	26.9	112.8

† Soil pH values were obtained by the 1:1 soil:water method.

‡ NO_3-N, P and K values were obtained using the method Mehlich-3.

Table 2. Soybean seed yield and plant height means by maturity group and planting date for Stillwater 2012 and 2013, and Perkins 2013.

Site-year	MG	Plant height			
		21-May	02-Jun	13-Jun	25-Jun
		cm			
Stillwater 2012	3.8	69 A ab	67 A a	44 B b	39 B b
	4.7	64 A b	67 A a	45 B b	41B b
	5.6	65 A b	62 A a	52 B b	44 B b
	6 (LJ)	63 A b	60 A a	62 A a	58 A a
	7 (LJ)	70 A ab	65 A a	65 A a	63 A a
	8 (LJ)	77 A a	69 A a	63 A a	65 A a
		24-May	3-Jun	15-Jun	27-Jun
		cm			
Stillwater 2013	3.8	75 A b	67 A a	53 B ab	39 C b
	4.7	71 A b	63 A ab	52 B bc	40 B b
	5.6	61 A c	56 A b	44 B c	45 B b
	6 (LJ)	73 A b	57 B b	61 B a	61 B a
	7 (LJ)	75 A b	61 B ab	59 B a	66 B a
	8 (LJ)	87 A a	64 B ab	60 B a	66 B a
		27-May	4-Jun	15-Jun	27-Jun
		cm			
Perkins 2013‡	3.8	53 B bc	69 A a	59 B a	39 C b
	4.7	49 BC bc	72 A a	58 B a	41 C b
	5.6	46 B c	66 A a	61 A a	42 B b
	6 (LJ)	52 B b	66 A a	63 A a	61 A a
	7 (LJ)	65 A ab	69 A a	64 A a	62 A a
	8 (LJ)	66 A a	70 A a	63 A a	64 A a

† Plant height means followed by same upper-case letters in the same row (within MG) and means followed by same lower-case letters in the same column (within planting date) are not significantly different at the 5% level within site-year.

‡ No supplemental irrigation was provided at the Perkins site.

Table 3. Maximum soybean canopy cover and cumulative thermal units by maturity group (MG) and planting date for Stillwater 2012 and 2013, and Perkins 2013.

Site-year	Planting date	Maturity group 3.8	4.7	5.6	6 (LJ)	7 (LJ)	8 (LJ)	
		Maximum canopy cover (%)						
Stillwater 2012	21-May	76	83	85	88	94	84	A†
	02-Jun	77	90	82	83	81	85	A
	13-Jun	76	80	81	87	90	95	A
	25-Jun	70	85	79	85	83	77	A
		b‡	a	a	a	a	a	
Stillwater 2013	23-May	86	87	87	92	90	96	A
	3-Jun	87	94	87	92	93	94	A
	15-Jun	83	87	80	87	90	93	B
	27-Jun	67	82	82	88	88	84	C
		c	c	bc	ab	ab	a	
Perkins 2013	27-May§	–	–	–	–	–	–	-
	4-Jun	90	93	93	97	99	95	A
	15-Jun	86	92	89	90	97	92	B
	27-Jun	79	88	83	95	86	86	C
		d	bc	dc	ab	a	bc	

† Planting dates with maximum canopy cover means across MG followed by same upper-case letters within site-year are not significantly different at the 5% level.
‡ Maturity groups with maximum canopy cover means across planting date followed by same lower-case letters within site-year are not significantly different at the 5% level.
§ Canopy cover measurements were not taken from first planting date (27-May) at Perkins 2013 due to poor plant stand.

Table 4. Soybean seed protein and oil concentration means by maturity group and planting date for Stillwater 2012 and 2013, and Perkins 2013.

		Seed protein content					Seed oil content				
Site-year§	MG	21-May	02-Jun	13-Jun	25-Jun		21-May	02-Jun	13-Jun	25-Jun	
		——— % ———					——— % ———				
Stw. 2012	3.8	34.7	34.0	33.8	34.1	B†	18.8	19.2	19.1	19.5	A
	4.7	33.9	33.9	33.4	33.0	BC	19.2	19.0	19.3	19.3	A
	5.6	33.8	32.6	33.7	33.6	C	19.7	20.0	19.6	18.2	A
	6 (LJ)	34.0	33.9	34.5	34.0	B	18.9	18.2	17.3	17.3	B
	7 (LJ)	34.4	33.9	34.1	33.3	B	17.9	17.3	16.9	17.3	B
	8 (LJ)	35.0	34.1	35.2	34.7	A	16.8	17.4	17.0	17.3	B
		a‡	a	a	a		a	a	a	a	
		24-May	3-Jun	15-Jun	27-Jun		24-May	3-Jun	15-Jun	27-Jun	
		——— % ———					——— % ———				
Stw. 2013	3.8	35.1	33.8	34.5	34.3	B	19.0	19.4	18.9	18.8	A
	4.7	34.6	34.5	34.3	33.6	B	19.5	19.3	18.7	19.8	A
	5.6	33.6	35.2	33.1	33.0	B	19.8	18.8	19.9	19.3 a	A
	6 (LJ)	35.9	35.8	35.0	36.2	A	18.0	17.5	17.5	17.0	B
	7 (LJ)	35.3	35.9	35.4	36.3	A	18.0	17.2	17.3	17.4	B
	8 (LJ)	35.5	36.5	35.8	35.1	A	17.9	16.8	16.9	17.2	B
		a	a	a	a		a	a	a	a	
		27-May	4-Jun	15-Jun	27-Jun		27-May	4-Jun	15-Jun	27-Jun	
		——— % ———					——— % ———				
Pks. 2013	3.8	32.0	33.2	32.5	30.5	C	18.9	19.1	18.7	20.4	A
	4.7	31.8	33.7	33.2	34.2	B	19.1	18.0	19.3	19.5	A
	5.6	32.2	29.9	33.9	30.9	C	19.1	20.3	18.9	20.8	A
	6 (LJ)	32.1	35.8	33.6	35.1	A	19.0	17.5	17.7	17.2	B
	7 (LJ)	35.0	35.7	35.6	35.3	A	18.4	17.5	17.2	17.5	B
	8 (LJ)	34.1	32.2	35.9	32.3	B	17.9	18.5	17.4	18.1	B
		a	a	a	a		a	a	a	a	

† Seed protein and oil concentration means across planting dates followed by same upper-case letters within site-year are not significantly different at the 5% level.
‡ Seed protein and oil concentration means across MG followed by same lower-case letters within site-year are not significantly different at the 5% level.
§ Site-year Stw. 2012 = Stillwater, 2012; Stw. 2013 = Stillwater, 2013; Pks. 2013 = Perkins, 2013.

Table 5. Soybean seed yield means by maturity group and planting date for Stillwater 2012 and 2013, and Perkins 2013.

Site-year	MG	Seed Yield means by MG by planting date			
		21-May	02-Jun	13-Jun	25-Jun
		Kg ha-1			
Stillwater 2012	3.8	2721 A a†	2500 A a	1284 B b	1033 B cb
	4.7	2530 AB a	2971 A a	1981 B a	1836 B a
	5.6	2899 A a	2950 A a	2477 AB a	1875 B a
	6 (LJ)	2679 A a	2945 A a	2186 AB a	1700 B a
	7 (LJ)	2443 A a	2674 A a	1388 B b	1133 B b
	8 (LJ)	1488 A b	1615 A b	1378 A b	762 B bc
		24-May	3-Jun	15-Jun	27-Jun
		Kg ha-1			
Stillwater 2013	3.8	1071 B c	1785 A a	1698 A bc	1721 A b
	4.7	1592 B bc	2344 A a	2510 A a	2006 AB ab
	5.6	1868 A b	1731 A a	1603 A bc	1080 B c
	6 (LJ)	3011 A a	1925 B a	1911 B b	2297 B a
	7 (LJ)	2661 A a	1941 B a	2195 AB ab	1970 B ab
	8 (LJ)	2151 A ab	1572 B a	1691 AB bc	1283 B c
		27-May	4-Jun	15-Jun	27-Jun
		Kg ha-1			
Perkins 2013‡	3.8	939 A a	886 A b	954 A b	764 A b
	4.7	984 A a	872 A b	1249 A ab	1124 A ab
	5.6	1198 A a	909 A ab	1062 A ab	891 A ab
	6 (LJ)	1525 A a	1039 A ab	1253 A ab	1257 A a
	7 (LJ)	1249 A a	975 A ab	1402 A a	1066 A ab
	8 (LJ)	1354 A a	1221 A a	1247 A ab	1018 A ab

† Seed yield means followed by same upper-case letters in the same row (within MG) and means followed by same lower-case letters in the same column (within planting date) are not significantly different at the 5% level within site-year.

‡ Irrigation was not available at Perkins site.

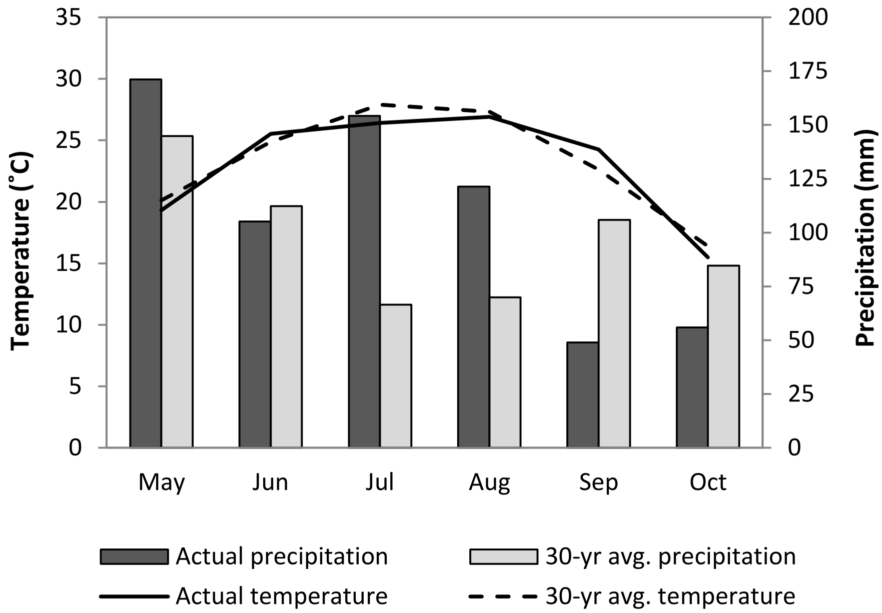

Figure 1. 2013 and 30-yr average rainfall and air temperature for Perkins, OK.

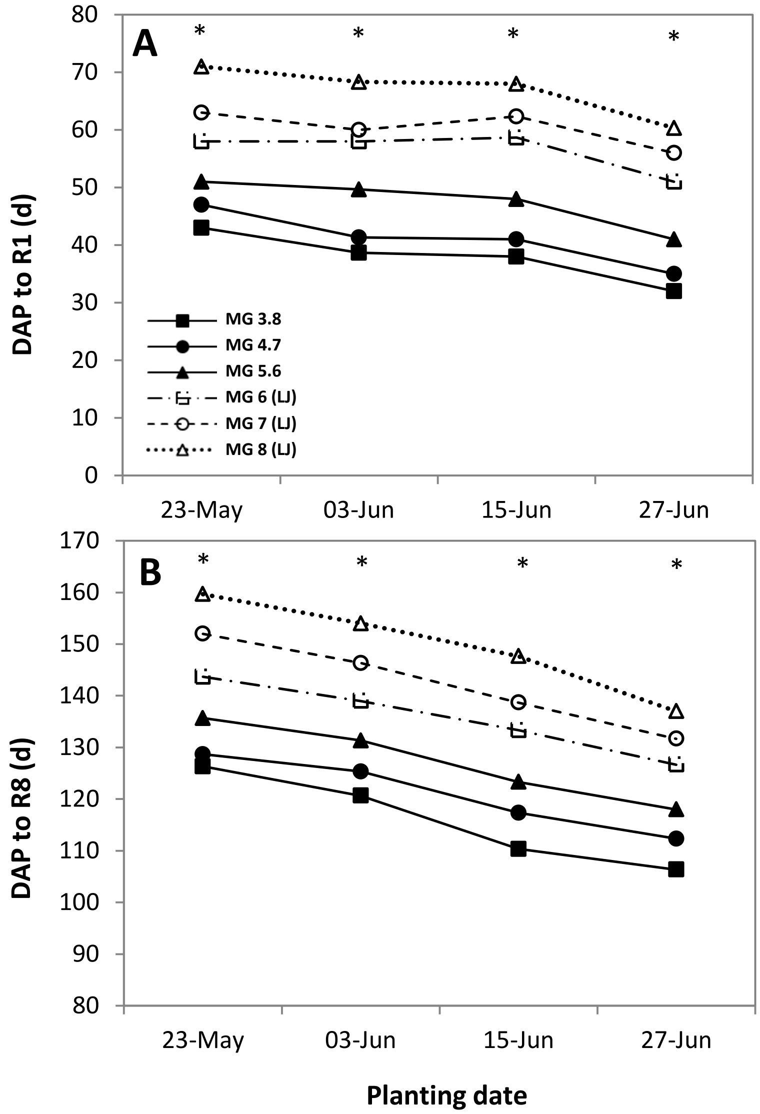

Figure 2. Days after planting to R1 (A) and R8 (B) growth stage (Fehr and Caviness, 1977) by maturity group (MG) and planting date. A "*" above a set of data points indicates the MGs differed in number of day after planting to R1 and to R8 within each planting date at 0.05 significance level. Actual values are displayed in Table B-1 of the appendices section.

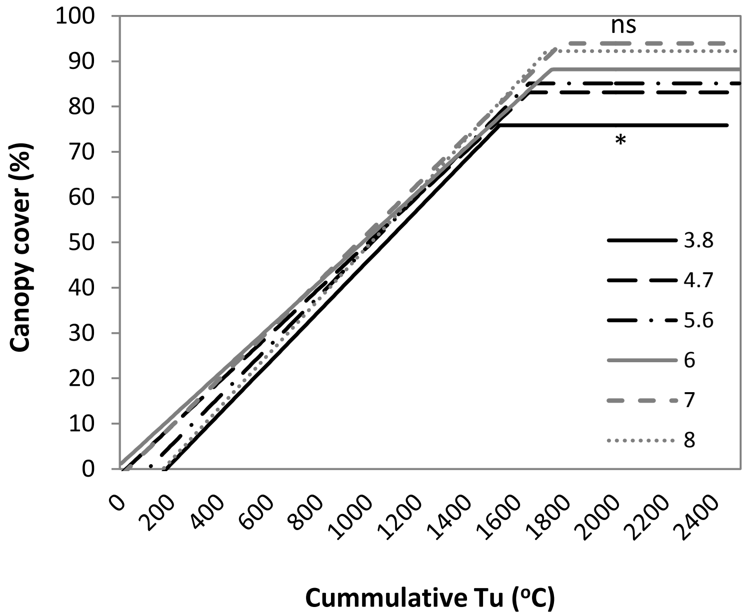

Figure 3. Maximum canopy cover by maturity group for planting date 23-May at Stillwater site in 2012. "*" Only MG 3.8 was different in maximum canopy cover at 0.05 significance level. "ns" All MG except 3.8 did not differ in maximum canopy cover.

CHAPTER IV

STARTER AND FOLIAR FERTILIZATION EFFECT ON LATE-PLANTED SOYBEAN YIELD IN THE SOUTHERN GREAT PLAINS

4.1 INTRODUCTION

Late-planted soybean has been a common practice in Southern Great Plains especially as a double crop following wheat harvest. Due to soybean photoperiod sensitivity, delayed soybean plantings commonly affect plants vegetative growth by shortening time before flowering, which potentially leads to poor yields (Knapp et al., 1980; Kane et al., 1997; Wesley et al., 1998). Tests over the last three years in Oklahoma have indicated a 1-2% drop in yield potential for every delayed planting day when planting after June 15 (Barreiro and Godsey, 2013). Supplemental fertilization has been a common practice among soybean producers to increase seed yield; however, starter N and foliar N-P-K applications have shown inconsistent response on soybean seed yield across several investigations. According to Kamprath (1974), soybean has low response to foliar N-P-K fertilization compared to other grain crops. However, Mallarino and Haq (2005) stated that foliar soybean fertilization with N-P-K, and other nutrients can benefit soybean growth, yield, and seed protein and oil concentration. Although soybean obtains most of the N required for growth through symbiotic fixation, there are studies describing that application of N as a “starter” fertilizer increased soybean growth and grain yield (Afza et al., 1987; Al-Ithawi et al., 1980; Eaglesham et al., 1983; Osborne and Riedell, 2006; Sorensen and Penas, 1978; Touchton and Rickerl, 1986; Wood et al., 1993). Research conducted in Alabama by Starling et al. (1998) showed increased response to starter N application on both growth and seed yield. However, other investigators have documented no response or negative response to starter N fertilization (Beard and Hoover, 1971; Deibert et al., 1979, Peterson and Varvel, 1989; Welch et al., 1973). In a study conducted in Texas by Sij et al. (1979), N applied as a starter fertilizer at planting had no effect on either vegetative growth or seed yield. Terman (1977) concluded that broadcasted N applied at early stages increased vegetative growth by 20%, but had no effect on seed yield.

Foliar fertilization of plants is a well-known practice that has been used for over 100 years (Borkert, 1987). With soybean, this practice has being broadly studied since the early 1970's. Most of these researches have addressed foliar fertilization of soybean during reproductive stages. During this phase, it is commonly observed reduction in root activity and increased depletion of nutrients and metabolites from other plant tissues being transferred to the seeds (Hanway, 1976). Therefore, supplementation of nutrients such as N, P, K, and S by foliar application during pod-filling can increase yields up to 31% (Garcia and Hanway, 1976). In a greenhouse study, Terman (1977) showed greater yield response by soil and foliar applied N,P,K, and S during pod-filling compared applications at early vegetative stages. However, when contrasting both application methods during pod-filling, greater yield was observed by N,P,K, and S applied to the soil, mainly due to pot watering favoring soil application and leaf burns impairing positive effects of foliar fertilization on yield.

The growth period when soybean most requires P, is between the V4 and R6 (Fehr and Caviness, 1977) stages, but the ideal would be a constant supplementation of this nutrient (Rosolem, 1982). However, P fertilization, although effective, may lead to increased lodging (Bharati et al., 1986). In this same study, K fertilization had same lodging effect but increased grain yield. Inconsistent results from soybean studies related to foliar fertilization with P and K are also commonly obtained. This lack of response can be correlated with sufficient amounts of P and K present in the soil limiting the effect of foliar fertilization (Haq and Mallarino, 2000).

Little research has focused in foliar fertilization of soybean during vegetative stages. In a study conducted in southeast Brazil, Rosolem (1982) found no grain yield increase when applying foliar fertilizers with 30 to 75 d after emergence, containing different N-P-K rates with or without micronutrients. At early critical stages, however, foliar N-P-K application at small rates could increase yields without impacting the N_2 fixation mechanism of soybean plants, if considered as a complement to soil fertility (Haq and Mallarino, 1998).

Fertilization practices in delayed planting soybean systems have also shown potential to minimize yield losses (Starling et al., 1998; Taylor et al., 2005). In late-planted soybean systems, which are usually associated with double-cropping (Lewis and Phillips, 1976; Egli et al., 1987), seed yield reduction is generally related to insufficient vegetative growth (Boerma and Ashley, 1982). Starling reported a yield increase of 150 kg ha^{-1} due to starter N application on late-planted soybean in Alabama. On the other hand, Touchton and Rickerl (1986) stated that the chances of increasing grain yield with starter fertilizers are reduced as planting date is delayed.

In the Southern Great Plains, there is little research and limited data related to starter and foliar fertilization of soybean. Moreover, for this region, no studies were found covering these practices on late-planted soybean system. Although there are controversies on the feasibility of these fertilization practices on soybean, we hypothesize that starter and foliar fertilization at specific development stages will have a positive response in growth and grain yield of late-planted soybean compared to treatments without fertilization. Therefore, the objectives of this study are to test different fertilizer sources applied following specific recommendations of timing and rates and evaluate their potential for increasing late-planted soybean yield in the Southern Great Plains.

4.2 MATERIAL AND METHODS

Four site-years were included in this study: Stillwater, OK (2011, 2012 and 2013) and Perkins, OK (2013). In Stillwater the trials were established on an Norge loam (fine-silty, mixed, active, thermic Udic Paleustolls) located at the Oklahoma State University Agronomy Research Station in Stillwater, OK (36°07'29.81" N, 97°06'15.04" W, elevation 270 m). In Perkins, the trial was conducted on a Teller loam (fine-loamy, mixed, active, thermic Udic Argiustolls) located at the Cimarron Valley Research Station in Perkins, OK (35°59'16.68" N, 97°02'46.28" W, elevation 279 m). Pre-plant soil samples were taken from 0 – 15 cm deep and results are shown in Table 1. The experiment was arranged in a RCBD with three replications (blocks), consisting of seven treatments: 1) 5.7 kg N ha^{-1} as ammonium polyphosphate applied in the furrow at planting. 2) 22.4 kg N ha^{-1} as urea broadcasted by hand at planting and at R1 stage. 3) 1.2 l *Bio-forge* (N,N'-diformyl urea) ha^{-1} foliar applied at V4 stage. 4) 1.2 l *SummaGrow* (humic+fulvic acid) ha^{-1} foliar applied at V4 stage. 5) 0.6 l *NutrivantPlus* (11-36-24+TE+FV) ha-1 foliar applied at V4 plus 0.6 l ha-1 at R2 stage. 6) 1.2 l *NutrivantPlus* (11-36-24+TE+FV) ha-1 foliar applied at V4. 7) No fertilizer applied. (Table 2). Fertilizer rates of starter N were based on previous study conducted in Oklahoma (Hedges, 2012). Ammonium polyphosphate was applied in the seed furrow at planting using a liquid fertilization system attached to the drill, and urea application was hand-broadcasted. Application timing and rate for foliar treatments, were based on product`s recommendation for soybean, and were performed using a CO2 mounted bicycle sprayer. To deliver 1.2 l ha-1 of product solution, sprayer was calibrated for speed of 5 km h^{-1} at

74 kpa pressure using a F80/0.4/3 standard flat fan nozzle. Pressure was reduced by 50% for applications of 0.6 l ha-1 of solution. *Bio-forge* and *SumaGrow* solution were sprayed without addition of water, while *NutrivantPlus*, a soluble fertilizer, was mixed with water following recommendation of 2 kg ha^{-1} of the product.

Plots were 1.5 by 7.6 m with a 0.19 m row spacing (7 rows). Asgrow glyphosate resistant soybean cultivar AG 5605 (MG 5.6) was sown 2.5 cm deep, on late June at a rate of 321 000 seeds ha^{-1} using a Hege small-plot conventional-drill (Winterstieger, Salt Lake City, UT). At all site-years, trials were conducted using conventional tillage practices, which were performed with an offset disk followed by a field cultivator. Soybean seeds were inoculated at planting with *Bradyrhisobium japonicum* (EMD BioScience, Brookfield, WI). Weed and insecr management practices were conducted according to Oklahoma State University Cooperative Extension recommended practices (Pratt et al., 2009). At all site-years, weeds were controlled with 2.2 kg ha^{-1} metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] and 0.8 kg ha^{-1} pendimethalin [N-(1-ethylpropyl)- 3,4-dimethyl-2,6-dinitrobenzenamine] pre plant followed by 1.12 kg ha^{-1} glyphosate [N-(phosphonomethyl) glycine3] post-emergence. Insect control was not necessary at these trials.

Supplemental irrigation was provided at Stillwater in both years to guarantee plant establishment and development throughout the summer. Sprinkler irrigation was managed from planting through R7 stage (Fehr and Caviness, 1977) with two applications per week, accounting for approximately 12.5 mm of water per application (100 mm mo^{-1}). This irrigation frequency and amount was used to reflect soybean crop water requirements (average evapotranspiration during growing season), considering the

30-yr average rainfall and soil water holding capacity at soybean effective root zone. No irrigation was available at Perkins site. Thirty-year average rainfall and air temperature for all site-years are shown in Figure 1. To determine seed yield, the center two rows of each plot were harvested using a Wintersteiger Delta plot combine (Wintersteiger Inc., Salt Lake City, UT) when plants reached maturity. Seeds were also collected for laboratory measures of moisture and plot weight and yield was adjusted to 130 g kg^{-1} moisture content. Statistical analyses were done using SAS software version 9.3 (SAS Institute, Cary, NC). Analyses of variance (ANOVA) were performed using the MIXED procedure of SAS to specifically determine seed yield differences among treatments. Least significant differences (LSDs) were determined at 0.05 significance level.

4.3 RESULTS AND DISCUSSION

Plant seed yield was analyzed separately for each site-year because Perkins site did not receive irrigation as in Stillwater. Thirty-year average rainfall and air temperature during the growing season (May – Oct) for all site-years are displayed in Figure 1. In Stillwater 2011, seed yield was not different (P = 0.63) when contrasting all fertilization treatments. None of these starter and foliar fertilization treatments resulted in yield increase compared to plots that did not receive any fertilization (control plots) (Figure 2a). In Stillwater 2012, seed yield comparisons among treatments resulted only in a marginal effect (P = 0.08) due large part to least squares means differences when comparing treatment with 1.2 l *Bioforge* solution ha^{-1} to treatment with 5.7 kg N ha^{-1} in the furrow and to treatment with 22.4 kg N ha^{-1} broadcasted. Treatment with *Bioforge* vs N in the furrow and *Bioforge* vs. N broadcasted had P = 0.003 and P = 0.04, and mean yield of 3244 vs. 2087 kg ha^{-1} and 3244 vs. 2554 kg ha^{-1}, respectively. At this site-year, the control treatment had significantly greater mean yield than treatment with N in the furrow (P = 0.05) (Figure 2b). For Stillwater 2013, seed yield results did not differ between all treatments (P = 0.63) (Figure 2c). Similarly to all three trials at Stillwater site, Perkins 2013 also had no seed yield response (P = 0.87) to none of the fertilization treatments, and treatments 7 (no fertilizer) yielded as much as those that received fertilizers (Figure 2d). In summary, neither starter N fertilization (in furrow or broadcasted) nor foliar fertilization (during vegetative or reproductive stages) resulted in yield increase compared to zero fertilization treatment, regardless of site-year.

Although many studies have shown increased yield response to starter N fertilization, specific soil and environmental characteristics, different from those present in our study, must be considered. For instance, research conducted in Alabama by Touchton and Rickerl (1986) obtained soybean yield increase by starter N fertilization only when residual soil P levels were low, which did occur in our study. Osborne and Riedell (2006) reported 6 % yield increase across three site-years in South Dakota in response to 16 kg N ha-1 as starter fertilizer; however, besides greater N rate, N was band applied, differing from our N placement methods. Moreover, Starling et al. (1998) showed approximately 150 kg ha^{-1} soybean yield increase in response to starter N in research conducted in Alabama on late-planted system; however, nitrogen rates were higher (50 kg N ha^{-1}) and urea was broadcasted and incorporated before planting. In agreement with our results, Haq and Mallarino, (1998) states that soybean yield response to starter fertilizers are not expressive when planting date is delayed. The authors explain that this lack of yield response in late plantings is associated to greater soil temperatures in these periods of the growing season.

In relation to foliar N-P-K fertilization, few studies have reported soybean yield increase in response to foliar fertilization during early vegetative stages (Haq and Mallarino, 1998) or during reproductive stages (Hanway, 1976; Garcia and Hanway, 1976). However, Haq and Mallarino (1998) declares that yield increments may be obtained only if foliar N-P-K fertilizers be applied as a complement for soil fertilization. Nonetheless, the lack of response in seed yield to starter and foliar fertilization resulted from our study is also described at several other investigations such as Sij et al. (1979) in which the authors concluded that N applied as a starter fertilizer at planting had no effect on either vegetative growth or seed yield in trials conducted in Texas. Terman (1977) also reported no seed yield response to foliar N fertilization during early vegetative stages, which was due to leaf burn. Similar lack of response to foliar N-P-K treatments observed in our study was also concluded by research conducted in the Southeastern Brazil with foliar N-P-K and N-P-K + micronutrients application (Rosolem et al., 1982).

The main reason for the lack of yield response to starter or foliar fertilization compared to control plots in our study is possibly because soil nutrients were present at sufficiency levels at all four site-years (Table 1) and these complement fertilizations were not in need (Haq and Mallarino, 1998), and/or due to high soil temperatures at late-planting in the case of starter N fertilizer (Haq and Mallarino, 1998) or during foliar applications causing apparently leaf burn (Terman, 1977).

4.4 CONCLUSIONS

Seed yield was not increased by any of the starter or foliar fertilization treatments compared to no fertilizer treatment. These results suggest that these fertilizer inputs are not a viable management practice to be considered on soils with nutrients at sufficiency levels on late-planted soybean system in the Southern Great Plains. However, as stated by other authors, yield response to either starter or foliar fertilization may become a feasible practice if viewed as a complement in case of soil nutrients are at low sufficiency levels for soybean crop production. In this sense, future research efforts would be critical in determining starter and foliar fertilization effects on late-planted soybean yield grown at low soil nutrient levels in the Southern Great Plains.

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Table 1. Soil pH, OM, and nutrients results from soil samples collected at prior to planting from all experiment sites in 2011 to 2013 in Oklahoma.

Year	Location	pH†	OM	Nutrients		
				NO_3-N‡	P‡	K‡
			%		mg kg^{-1}	
2011	Stillwater	5.8	0.7	7.5	32.0	123.5
2012	Stillwater	6.2	0.7	8.0	38.0	131.5
2013	Stillwater	7.2	0.9	6.0	88.0	133.5
	Perkins	6.5	0.8	2.0	26.5	126.0

† Soil pH values were obtained by the method 1:1.

‡ NO_3-N, P and K values were obtained using the method Mehlich-3.

Table 2. Fertilization treatments, source, main nutrient, rates, and application timing based on recommendations. Treatment were similar at all four site-years.

Treatm.	Fertilization type	Fertilizer Source	Main Nutrient	Application Rate	Application timing
				—kg ha^{-1}—	
1	Starter	Ammonium polyphosphate (10 -34-0)	N-P	5.7	in furrow
2	Starter	Urea (46-0-0)	N	22.4	At planting and R1
				— l ha^{-1} §—	
3	Foliar	*Bio-Forge* (N,N'-diformyl urea)	N	1.2	V4
4	Foliar	*SummaGrow* (humic+fulvic acid)	OM/NPK	1.2	V4
5	Foliar	*NutrivantPlus* (11-36-24 +TE†+FV‡)	NPK+micro	0.6	V4 and R2
6	Foliar	*NutrivantPlus* (11-36-24+TE+FV)	NKP+micro	1.2	R2
7	Control	No fertilizer	–	–	–

† "TE" Trace elements (micronutrients).

‡ "FV" '*FertiVant'* (built-in adjuvant).

§ Rate of solution in liters ha^{-1}.

¶ Soybean developmental stage according to Fehr and Cavinness (1977).

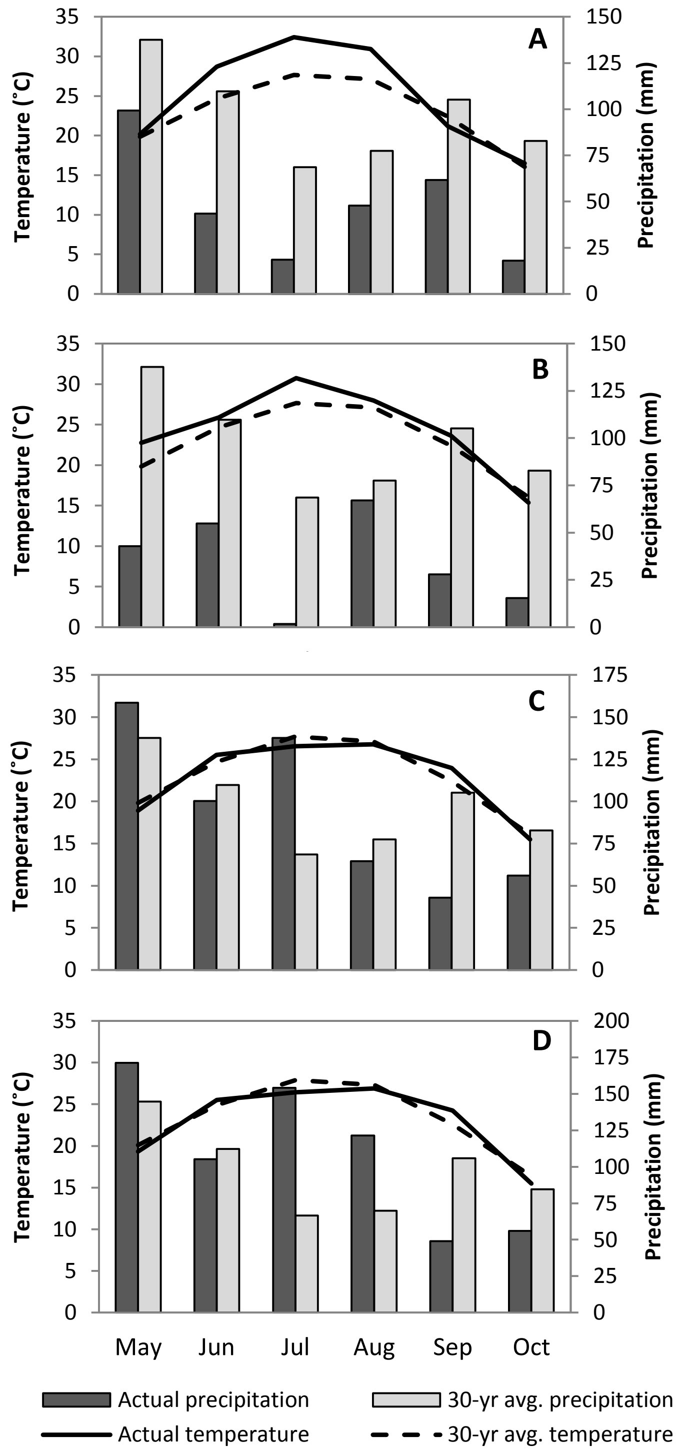

Figure 1. Actual and 30-yr average precipitation and air temperature for Stillwater, OK in 2011 (A), 2012 (B), and 2013 (C), and Perkins, OK in 2013 (D).

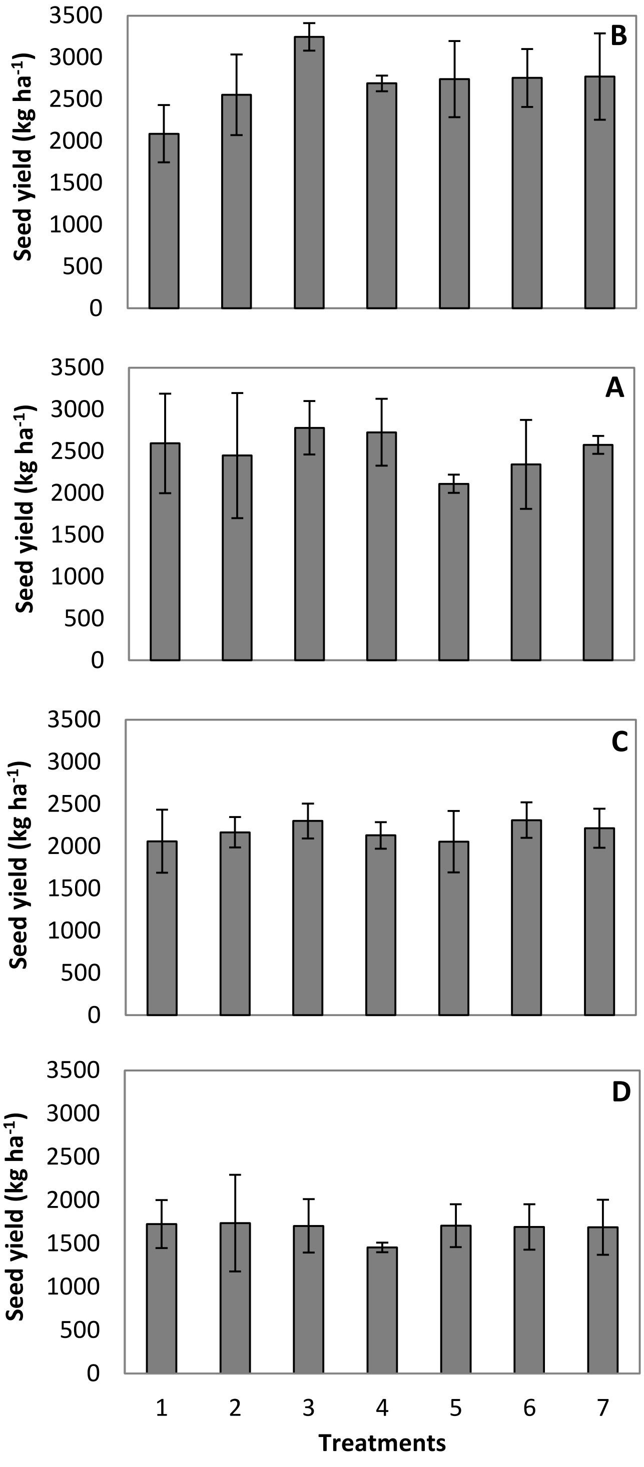

Figure 2. Seed yield means and standard deviation error bars for treatments 1 (5.7 kg N ha^{-1} in furrow), 2 (22.4 kg N ha^{-1} broadcasted at planting and at R1), 3 (1.2 l N,N'-diformyl urea ha^{-1} at V4), 4 (1.2 l humic+fulvic acid ha^{-1} at V4), 5 (1.2 l NPK solution ha^{-1} at R2; 6) 0.6 l NPK solution ha^{-1} at V4 and R2), 7 (no fertilizer applied), for Stillwater, OK in 2011 (A), 2012 (B), and 2013 (C), and Perkins, OK in 2013 (D).

CHAPTER V

LATE-PLANTED SOYBEAN YIELD AS AFFECTED BY ROW SPACING, SEEDING RATE, AND MATURITY GROUP UNDER IRRIGATED CONDITIONS IN OKLAHOMA

5.1 INTRODUCTION

Increased soybean commodity prices and new cultivars have led producers to expand soybean cultivation outside traditional production regions. Introduction of soybean to relatively new areas such as the southern Plains, into drier climates has created the need for management practices unique to the region to overcome low yield along with adverse environmental conditions. Winter wheat is the dominant cropping system in the state; thus, soybean is often planted late as a double crop following wheat harvest (Barreiro and Godsey, 2013). In Oklahoma for instance, late-planting has been a practice contributing to yield reduction. Due to soybean photoperiod sensitivity, delayed planting leads to a shortened time for soybean plants to complete vegetative growth. In these cases, critical reproductive development phases will likely coincide with periods of hot and dry environmental conditions, which will potentially negatively impact soybean yield (Torres et al., 2013; Egli and Bruening, 2000; Wesley, 1999; Knapp et al., 1980). Tests in 2009 and 2010 in Oklahoma indicated a 1-2% drop in yield potential for every day delay in planting after 15 June (Barreiro and Godsey, 2013). Therefore, better management practices are required for late-sown soybean in Oklahoma to minimize yield losses and to optimize profits. Optimal seeding rate, row spacing, and maturity group (MG) selection combined with irrigation, are management practices that might improve yield of late-planted soybean that will be discussed in this manuscript. Soybean production began to switch from wide (≥ 76 cm) to narrow row spacing (< 76 cm) in the early 1990's. The benefits of narrow row spacing compared to wide row spacing have been well documented (Beatty et al., 1982; Copper, 1977; Ethredge et al., 1989; Lehman and Lambert, 1960; Parks et al.; 1982; and Weber et al., 1966). However, the introduction and wide spread use of glyphosate-resistant soybean cultivars since 1996 led to a significantly increase in soybean seed costs. Higher seed costs generated interest in reaching optimum plant population to maximize yield while reducing seed costs (Popp et al., 2006; Lee et al., 2008).

Although many researchers have reported potential for increasing soybean yield by narrowing row spacing, this practice is not completely adopted due to the low response of corn (*Zea mays* L.) yield when planted in narrow rows (Hallman and Lowenberg-DeBoer, 1999; Westgate et al., 1997). Since many producers alternate soybean and corn production, adopting narrow-spacing soybean would result in the need to constantly change their planter's row spacing or purchase higher cost equipment with additional row units for easy transaction between wide and narrow rows (De Bruin and Pederson, 2008). An important advantage of managing soybean at narrow row spacing is the increase in light interception due to greater canopy leaf area, since plants are more equidistant. Increased light interception by the plants leads to greater dry matter production, which ultimately may translate to greater seed yields (Shibles and Weber, 1966; Weber et al., 1966; Edwards et al., 2005). Furthermore, when soybean canopy closure is achieved sooner due to narrow row spacing, weed control (Siemens and Oschwald, 1978; Buhler et al., 1990; Yelverton and Coble, 1991; Norsworthy and Oliver, 2009; Edwards and Purcell 2005) and soil moisture conservation can be increased (Elmore, 1987). While soybean production being conducted under narrow row spacing has proved its benefits, some studies document that the yield increase is dependent on genotype (Grau et al., 1994; Weber et al. 1966), year and location (Lueschen et al., 1992), and planting date along with tillage system (Oplinger and Philbrook, 1992).

Besides the effect of row spacing on soybean yield, seeding rate also affects yield (Edwards and Purcell 2005, Board, 2000; Ethridge et al., 1989; Parvez et al., 1989; Egli 1988; Cooper, 1977; Shibles and Weber, 1966; Wiggans, 1939). Researches such as Philbrook et al. (1991), Oplinger and Philbrook (1992), and Popp et al. (2006) demonstrated that soybean yield can be significantly impacted by poor emergence and final stand and, increasing seeding rate is a common strategy to overcome this source of yield loss. Through narrowing row spacing, optimum seeding rate can be potentially increased since the use of ground area is being maximized (Oplinger and Philbrook, 1992; Weber et al., 1966); however, excessive increase in plant population can also decrease light interception since plant leaf area is decreased (Board, 2000; Edwards et al., 2005; Purcell et al., 2002). Another important reason for poor soybean yield at very high seeding densities is the increased propensity for lodging, which can reduce yield as much as 22% (Noor and Caviness, 1980). At high population densities, competition for solar radiation generally results in taller soybean plants and with thinner stems compared to plants at reduced populations; therefore, these plants are more likely to lodge (Cooper 1981; Mancuso and Caviness, 1991). Lodging in tall soybean plants also can be aggravated by heavy rainfalls and strong winds (Board, 2000), which are common occurrences late in the growing season for the Southern Great Plains.

Soybean canopy at specific row spacing is well known to depend on plant density and leaf expansion (Girardin and Tollenaar, 1994; Loomis et al., 1968; Tetio-Kagho and Gardner, 1988). Accordingly, soybean plants have greater branching and leaf area production at reduced plant density, which favors greater light interception per plant compared to increased plant density (Forountan-pour et al., 1999; Weber et al., 1966). Another important factor influencing soybean vegetative growth and yield is MG selection along with cultivar growth habit. Cultivars with the indeterminate growth habit, which is characterized by the vegetative growth still occurring at early reproductive stages, are usually from early MGs (I – IV). These MGs have been well studied in midsoutherb U.S. (Parvez et al., 1989) and has shown yield increases when planted at narrow row spacing as reported by Gardner (1978) and Beuerlein and Ryder (1981), for instance. Conversely, cultivars with the determinate growth habit, which is characterized by the vegetative growth ceasing at the beginning of reproductive stages, are usually from late MGs (5 to 8), predominantly used in southern latitudes of the U.S. Some studies with these late MGs did not show a positive response to narrow row widths (Hartwig, 1957; Smith, 1968; Smith and Hinson, 1969). Other investigators reported yield increase at narrow rows in studies conducted in the southern U.S. (Hodges et al., 1983; Smith and Hinson, 1969; Boquet et al., 1982).

Although, the positive effect of supplemental irrigation on soybean yield is well documented since early studies such as Whitt (1954), Spooner (1961), and Somerhalder and Schieusener (1960), there is little research contrasting determinate and indeterminate soybean cultivars at different row spacing and seeding rate in the southern Plains. Moreover, no research was found studying these management practices on late-planting systems under irrigated conditions in this region. We hypothesize that greater seed yield response to indeterminate cultivar planted at narrow rows and increased seeding rate will be obtained compared to the other management treatments. Therefore, the objectives of this study were to determine the optimum soybean maturity group, row spacing, and seeding rate to reach optimal yield in late-planted systems under irrigated conditions in the Southern Great Plains.

5.2. MATERIALS AND METHODS

This field study was conducted over three growing seasons in Stillwater, OK from 2011 to 2013. The trial was established on an Easpur loam (fine loamy, mixed, superactive, thermic Fluventic Haplustolls) located at the Oklahoma State University (OSU) Agronomy Research Station (36°07’28.52” N, 97°06’12.93” W, elevation 266 m). The experimental design was a RCBD with three replications. Main effects consisted of two cultivars of different maturity groups (MG, 4.8 and 5.6), two row spacing (0.19 and 0.76 m), and three seeding rates (247,000, 346,000, and 445,000 seeds ha-1). Plots were 3 m wide by 7.6 m long, accounting for 4 and 16 rows per plot, for the 0.76 and 0.19 m row spacing, respectively.

Based on the yield performance from previous studies around Oklahoma (Barreiro and Godsey, 2013), glyphosate-resistant soybean cultivars “REV48R22” (MG 4.8), of indeterminate growth habit, and “AG5632” (MG 5.6), of determinate growth habit, were selected to be used at all three years of study. Plots at all three years were sown on late June (26th – 28th) at 2.5 cm deep using a Hege small-plot conventional-drill (Winterstieger, Salt Lake City, UT) with 0.19 m row spacing, or a Monosem vacuum planter (Monosem, Inc. Edwardsville, KS) with four rows for 0.76 m row spacing treatments. Prior to planting, soybean seeds were inoculated with *Bradyrhisobium japonicum* (EMD BioScience, Brookfield, WI). Soil samples were taken prior to planting (Table 1), and no supplemental soil fertilization was required at any of the study years according to the Oklahoma State University Cooperative Extension recommendations (Pratt et al., 2009). Weed control management practices were also conducted according to Oklahoma State University Cooperative Extension recommended practices (Pratt et al., 2009). At all years weeds were controlled with 2.2 kg ha^{-1} metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] and 0.8 kg ha^{-1} pendimethalin N-(1-ethylpropyl)- 3,4-dimethyl-2,6-dinitrobenzenamine pre-emergence, plus a post-emergence application of 1.12 kg ha^{-1} glyphosate [N-(phosphonomethyl) glycine3] during vegetative stages. Insect control was not necessary at any of the study years.

In general, a fully irrigated soybean uses between 500 to 650 mm of water throughout the growing season (Kranz and Specht, 2012). Considering that soil moisture is lower later in the season compared to early season (Helsel and Helsel, 1993; Egli and Bruening, 2000; Torres et al., 2013), 650 mm was used as the base amount of total water required in each growing season in Oklahoma. Irrigation occurred three times per week and water amounts in each application were calculated weekly by subtracting previous rainfall amounts since planting from the total required (650 mm), then dividing the result by the number of weeks left to R7 stage (Fehr and Cavinness, 1977). Finally the water amount to be applied within a given week was divided by three to result in the water amount in each application. Irrigation was delayed whenever forecasts for rainfall were greater than 50 % probability for the day or next day of scheduled irrigation, and in case of rain, application water amounts were recalculated. Sprinkler irrigation was managed from planting through the beginning of R7 stage.

To determine seed yield, the whole plots were harvested when plants reached physiological maturity (R8) using a Wintersteiger Delta plot combine (Wintersteiger Inc., Salt Lake City, UT). The combine simultaneously recorded seed yield, seed moisture and test weight of each plot. Seeds were also collected for laboratory measures of moisture and plot weight; then, yield was adjusted to a moisture content of 130 g kg^{-1}. Seed yield and maximum percent canopy cover data were analyzed using SAS software version 9.3 (SAS, 2008). Analyses of variance (ANOVA) were performed separately for each site-year using the GLIMMIX procedure of SAS to determine differences in seed yield by maturity groups, row spacing, and seeding rate and also their interaction. Least significant differences (LSDs) were determined at 0.05 significance level.

5.3. RESULTS AND DISCUSSION

Daily rainfall and average temperatures during each growing season (May – Oct) were recorded by a Mesonet station, approximately 800 m from the trial. The Oklahoma Mesonet is a world class environmental monitoring network across the state of Oklahoma. Monthly actual and 30-yr cumulative rainfall and average air temperatures are displayed in Figure 1. Although soybean water requirements increase during reproductive stages compared to vegetative stages (Whitt, 1954; Spooner, 1961; Ashley and Ethridge, 1978; Pratt et al., 2009), irrigation in this study did not prioritize reproductive stages. This was due to the lower rainfall amounts generally observed during July, coinciding with early vegetative stages as planting date was late-June.

Analysis of variance in seed yield among treatments showed no yield response to either row spacing ($P = 0.62$) or seeding rate ($P = 0.28$). The interactions among treatments also resulted in no yield difference. (Table 2). However, soybean seed yield was responsive to MG ($P < 0.01$). Maturity group 4.8 resulted in approximately 25% greater yield compared to MG 5.6 (2620 vs. 1980 kg ha^{-1}). The yield advantage of cultivar *REV48R22* (MG 4.8) compared to *AG5605* (MG 5.6) was mainly due its indeterminate growth habit. Frequent irrigation during the extended flowering period of *REV48R22* cultivar possibly minimized the effect on plants by high temperatures, which were present during August each year of study. Thus flower abortion was probably avoided. The extended plant growth period may have favored vegetative growth and consequently seed yield. Also, because of the irrigation was quitted at same time, MG 5.6 may have lost some yield increase, since it reached R7 stage approximately 8 d after MG 4.8. In a previous study conducted under rainfed conditions in Oklahoma during 2009 and 2010 growing seasons, Barreiro and Godsey (2013) reported that same cultivars with MG 4.8 and 5.6 planted on late-June produced average of 1830 and 1565 kg ha^{-1}, respectively, across the two years of study. Based on this report, an estimated yield advantage of approximately 30 and 20 % for MG 4.8 and 5.6, respectively, can be noticed due to irrigation. For both MGs, a slight increase in seed yield was observed as seeding density increased, but these differences were not significant. Regarding row spacing, contradicting our findings, Boerma and Ashley (1982) and Heatherly (1988) concluded from studies conducted in Georgia and western Mississippi, respectively, that narrow row spacing had greater positive yield response to irrigation than wide rows, although Heatherly (1988) stated that this response was not consistently significant across the two years of trial. Helsel and Helsel (1993), however, demonstrated that to fully reach maximum seed yield potential under irrigation system, slightly reduction in soybean seeding rates and wide rows were crucial. The authors justify these management practices by stating that soybean plants tend to obtain more branches per plant and also avoid yield losses by lodging, common at narrow rows, which was also reported by Cooper (1981) and Mancuso and Caviness; (1991).

5.4. CONCLUSION

In this study, seed yield of late planted soybean under irrigation was affected only by MG. Seeding rate and row spacing had no effect on yield. Average yield of MG 4.8, across row spacings and years was 2620 kg ha^{-1}, which was 25 % greater than MG 5.6 yield (1980 kg ha^{-1}). In comparison with previous work in Stillwater, OK using the same cultivars and planting period, irrigated soybean produced 30 and 20 % greater seed yield for MG 4.8 and 5.6, respectively, than in a rainfed system. However, seed yield tends to significantly decrease as planting date is delayed after June, even with supplemental irrigation (Boerma and Ashley, 1982). Our data suggest that when planting soybean around late-June in Oklahoma under irrigation, an indeterminate cultivar has greater yield potential than a determinate cultivar, regardless of row spacing and seeding rate. Therefore, further investigations focusing in: 1) determine yield difference trends between indeterminate and determinate cultivars by adding more cultivars, 2) irrigate MGs independently until they reach R7 stage, so that each MG might express its full yield potential to be compared among them, and 3) evaluate, from same trials, yield differences between irrigated and non-irrigated systems at late plantings in Oklahoma, so that the feasibility of adopting irrigation in this system can be determined, are critical for making recommendations to soybean producers in Oklahoma.

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Table 1. Soil pH, OM, and nutrients results from soil samples collected at prior to planting from 2011 to 2013 in Stillwater, OK.

			Nutrients		
Year	pH†	OM	NO_3-N‡	P‡	K‡
		%	mg kg^{-1}		
2011	5.8	0.7	7.5	32.0	123.5
2012	5.8	1.3	10.3	49.1	163.4
2013	6.4	1.1	8.9	25.4	122.8

† Soil pH values were obtained by the method 1:1.

‡ NO_3-N, P and K values were obtained using the method Mehlich-3.

Table 2. Significance of *F* values from analysis of variance of seed yield within each site-year.

Source of variation	F value	Pr > F
Maturity Group (MG)	9.57	**
Row spacing (RS)	0.03	NS
MG x RS	0.14	NS
Seeding rate (SR)	0.62	NS
MG x SR	0.05	NS
RS x SR	0.19	NS
MG x RS x SR	0.36	NS

** Indicates significance at $P \leq 0.01$.

† NS, not significant at 0.05 probability level.

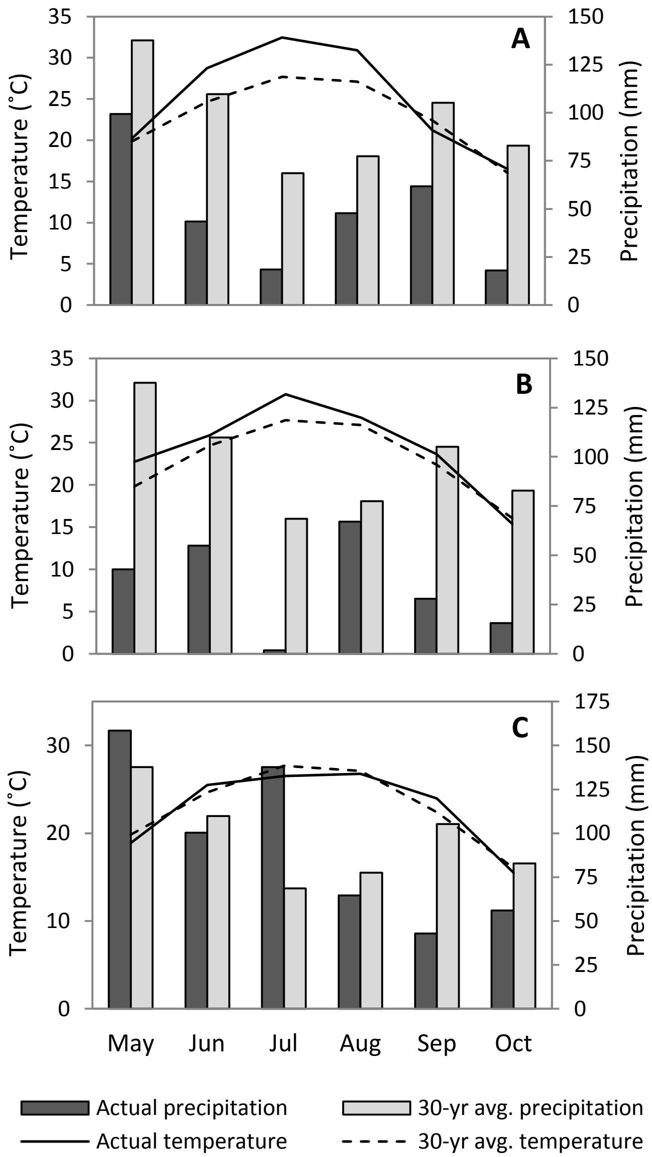

Figure 1. Monthly actual and 30-yr average precipitation and air temperature for Stillwater, OK during the growing season of 2011 (A), 2012 (B), and 2013 (C).

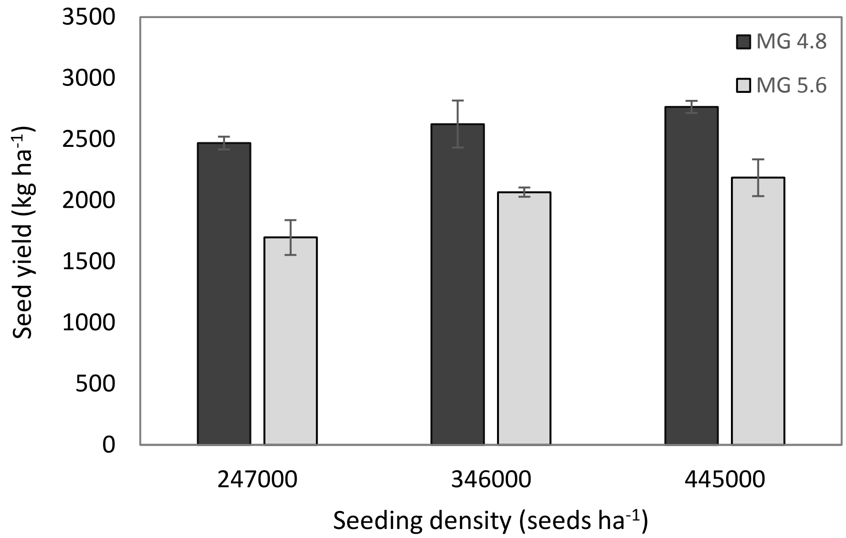

Figure 2. Soybean seed yield of MG 4.8 and 5.6 as a function of seeding density, averaged across row spacing and site-year. Standard deviation error bars were calculated between mean yield of 19 and 76 cm row spacing within MG and seeding density.

GENERAL CONLUSIONS

Average low soybean yield on late-planted system in the Southern Great Plains, can be explained by less favorable environmental conditions for soybean production, with scarce rainfalls, high temperatures, and short photoperiod late in the season. Results obtained from our studies shows that some management practices can significantly affect yield and vary according to environmental conditions. These results suggest that under water-limited environments, wide row spacings (38 or 76 cm) may have greater yields than 19 cm rows, seeding rate of 198,000 seeds ha-1 can have similar yield to greater seeding rates, thus, partial economic return can be increased by the reduced seed costs. Similar results were observed on the irrigated system, except that narrow row spacing (19 cm), under well supplied water conditions, can also be considered as a management practice to be used, resulting in similar yields than 76 cm rows. Greater yields were observed under irrigated vs. non-irrigated conditions. In this case, planting equipment availability can be the decision factor. The use of a late cultivar of indeterminate growth habit, as the case of the MG 4.8 cultivar, has also a slightly greater yield potential compared to a determinate cultivar such as MG 5.6, regardless of water regime.

The use of soybean cultivars of late MG carrying the long juvenile (LJ) trait, as a strategy to increase yield in late planting by the increased growth period, resulted in increased vegetative production but showed no seed yield advantage over well adapted cultivars of MG 4.7 and 5.6. The yield of these LJ lines did not increase at the same proportion of their vegetative production, possibly due to the excessively extended vegetative period and growth, in which generally, insufficient carbohydrates were being available for seed production. Regarding starter and foliar fertilization management on late-planted soybean in the southern Plains region, our data suggest that these fertilizer inputs are not a viable management practice to be considered on soils with nutrients at sufficiency levels for soybean. However, as stated by other authors, yield response to either starter or foliar fertilization may become a feasible practice if viewed as a complement in case of soil nutrients concentrations are lower than sufficiency levels.

Through our research studies, we can conclude that when soybean is planted late in the season (after mid-June) in the Southern Great Plains, management practices such as row spacing, maturity group selection, and irrigation can significantly increase yields in this non-optimal soybean production system.

APPENDICES

CHAPTER II

Table A-1. Soil pH, OM, and nutrients results from soil samples collected at prior to planting from all experiment sites in 2011 to 2013 in Oklahoma.

				Nutrients		
Year	Location	pH†	OM	NO_3-N‡	P‡	K‡
			%	mg kg^{-1}		
2011	Haskell	6.0	1.2	3.5	31.5	83.5
2012	Stillwater	7.0	1.3	11.0	31.5	136.0
2013	Haskell	6.4	1.2	9.5	31.0	112.5
	Stillwater	6.9	0.9	10.5	59.5	119.5
	Perkins	5.5	1.0	7.5	145.5	149.0

† Soil pH values were obtained by the method 1:1.

‡ NO_3-N, P and K values were obtained using the method Mehlich-3.

Table A-2. Soybean maturity groups, row spacing, and seeding rates used at all five site-years in Oklahoma.

Treatment	Maturity Group	Row Spacing	Seed Rate
		cm	Seeds ha^{-1}
1	4.8	19	198,000
2			260,000
3			321,000
4			383,000
5		38	198,000
6			260,000
7			321,000
8			383,000
9		76	198,000
10			260,000
11			321,000
12			383,000
13	5.6	19	198,000
14			260,000
15			321,000
16			383,000
17		38	198,000
18			260,000
19			321,000
20			383,000
21		76	198,000
22			260,000
23			321,000
24			383,000

Table A-3. Soybean seed yield by maturity group, row spacing and seeding rate within each site-year in Oklahoma.

				Seed Yield			
			Row	Seeding rate (seeds ha^{-1})			
Year	Location	MG	Spacing	198000	260000	321000	383000
			cm	____________Kg ha-1___________			
2011	Haskell	4.8	19	705	614	815	593
			38	739	663	1051	579
			76	804	575	665	688
		5.6	19	556	671	706	708
			38	626	692	663	618
			76	667	577	583	802
2012	Stillwater	4.8	19	589	658	925	895
			38	852	717	853	967
			76	691	748	701	635
		5.6	19	881	1053	1037	1124
			38	1074	1250	1423	1416
			76	1028	1085	1108	1096
2013	Haskell	4.8	19	717	793	727	726
			38	866	880	846	760
			76	726	794	801	743
		5.6	19	633	551	579	516
			38	813	691	573	580
			76	724	650	878	686
	Stillwater	4.8	19	919	1086	1149	1248
			38	1750	1772	1670	1778
			76	1749	2042	2047	1963
		5.6	19	1085	1164	1151	1303
			38	1542	1396	1629	1582
			76	1295	1379	1410	1291
	Perkins	4.8	19	1005	894	946	884
			38	1011	923	927	893
			76	965	911	916	1032
		5.6	19	527	714	617	706
			38	635	783	755	954
			76	812	1028	857	938

Table A-4. Canopy cover at maximum vegetative growth for MG 4.8 and 5.6 soybean cultivars for each row spacing and seeding rate within site-year.

				Canopy cover at maximum vegetative growth			
				Seeding Rate (plants ha^{-1})			
Year	Location	MG	Row Spacing	198000	260000	321000	383000
			cm		%		
2012	Stillwater	4.8	19	88	90	93	87
			38	78	82	77	75
			76	58	66	67	68
		5.6	19	92	95	90	89
			38	88	89	74	75
			76	88	59	71	71
2013	Stillwater	4.8	19	95	99	98	99
			38	87	95	80	65
			76	83	59	71	71
		5.6	19	95	95	98	97
			38	93	96	74	73
			76	80	85	75	80
2013	Stillwater	4.8	19	85.7	90.0	89.1	90.7
			38	88.0	82.5	75.9	90.4
			76	91.2	87.5	85.9	81.1
		5.6	19	94.7	79.3	92.7	91.7
			38	90.5	83.2	86.1	84.1
			76	86.4	86.5	85.9	85.7

Table A-5. Partial economic return of MG 4.8 soybean cultivar by row spacing and seeding rate within site-year. Partial economic return was calculated as the product of soybean commodity price in US$ kg^{-1} and yield in kg ha^{-1} subtracted by the sum of seed and transportation costs in US$ ha^{-1}.

			Partial Economic Return			
		Row	Seeding rate (seed ha^{-1})			
Year	Location	Spacing	198000	260000	321000	383000
		cm	US$ ha-1			
2011	Haskell	19	284	267	314	181
		38	334	242	414	224
		76	350	231	238	228
2012	Stillwater	19	226	369	251	459
		38	357	269	316	352
		76	251	314	240	186
2013	Haskell	19	290	306	253	231
		38	364	350	312	248
		76	294	307	290	240
	Stillwater	19	390	453	463	491
		38	805	795	723	755
		76	804	929	911	848
	Perkins	19	433	357	362	310
		38	437	371	353	314
		76	413	365	347	383

Table A-6. Partial economic return of MG 5.6 soybean cultivar by row spacing and seeding rate within site-year. Partial economic return was calculated as the product of soybean commodity price in US$ kg^{-1} and yield in kg ha^{-1} subtracted by the sum of seed and transportation costs in US$ ha^{-1}.

			Partial Economic Return			
		Row	Seeding rate (seed ha^{-1})			
Year	Location	Spacing	198000	260000	321000	383000
		cm	US$ ha-1			
2011	Haskell	19	202	235	230	163
		38	237	246	208	162
		76	257	255	185	254
2012	Stillwater	19	534	630	640	632
		38	668	688	880	817
		76	685	652	579	563
2013	Haskell	19	240	175	166	111
		38	330	312	163	143
		76	285	225	315	196
	Stillwater	19	465	481	451	504
		38	693	597	590	527
		76	570	588	580	498
	Perkins	19	187	257	185	206
		38	241	291	254	329
		76	329	413	305	322

Table B-1. Total number of day after planting for each maturity group (MG) to reach R1 stage (flowering) and R8 stage (maturity) at each planting date within site year in Oklahoma.

		Days after planting to R1				Days after planting to R8			
		Planting date				Planting date			
Site-year	MG	21-May	02-Jun	13-Jun	25-Jun	21-May	02-Jun	13-Jun	25-Jun
Stw_12	3.8	43	37	35	32	127	120	111	107
	4.7	49	40	38	36	130	125	117	113
	5.6	53	50	48	40	139	133	124	119
	6 (LJ)	59	58	57	53	148	138	132	128
	7 (LJ)	64	60	59	60	155	147	136	131
	8 (LJ)	72	66	66	63	162	155	146	134
		23-May	3-Jun	15-Jun	27-Jun	23-May	3-Jun	15-Jun	27-Jun
Stw_13	3.8	43	40	36	32	130	124	111	105
	4.7	46	42	37	34	133	128	118	110
	5.6	49	49	47	41	137	133	122	116
	6 (LJ)	56	61	58	49	144	142	136	124
	7 (LJ)	62	64	60	53	150	146	141	130
	8 (LJ)	74	71	69	59	160	155	151	140
		27-May	4-Jun	15-Jun	27-Jun	27-May	4-Jun	15-Jun	27-Jun
Pks_13	3.8	42	39	37	32	122	118	109	107
	4.7	46	42	37	35	123	123	117	114
	5.6	49	50	47	42	131	128	124	119
	6 (LJ)	56	55	57	51	139	137	132	128
	7 (LJ)	61	56	60	54	151	146	139	134
	8 (LJ)	72	68	69	59	157	152	146	137

Table B-2. Maximum canopy cover and cumulative thermal units (*Tu*) from planting to maximum canopy cover for each maturity group and planting date within site-year in Oklahoma.

Year	Location	Planting date	3.8	4.7	5.6	6 (LJ)	7 (LJ)	8 (LJ)
			Maturity group					
			Maximum canopy cover (%)					
2012	Stillwater	21-May	76	83	85	88	94	84
		02-Jun	77	90	82	83	81	85
		13-Jun	76	80	81	87	90	95
		25-Jun	70	85	79	85	83	77
			Cummulative *Tu* (^{o}C)					
		21-May	1580	1650	1650	1720	1780	1700
		02-Jun	1390	1580	1560	1580	1560	1540
		13-Jun	1380	1420	1470	1390	1410	1400
		25-Jun	1150	1270	1260	1260	1350	1370
			Maximum canopy cover (%)					
2013	Stillwater	23-May	86	87	87	92	90	96
		3-Jun	87	94	87	92	93	94
		15-Jun	83	87	80	87	90	93
		27-Jun	67	82	82	88	88	84
			Cummulative *Tu* (^{o}C)					
		23-May	1250	1310	1370	1320	1360	1370
		3-Jun	1150	1380	1260	1280	1330	1280
		15-Jun	1260	1260	1220	1310	1260	1320
		27-Jun	950	1110	1100	1160	1140	1060
			Maximum canopy cover (%)					
2013	Perkins	27-May	–	–	–	–	–	–
		4-Jun	90	93	93	97	99	95
		15-Jun	86	92	89	90	97	92
		27-Jun	79	88	83	95	86	86
			Cummulative *Tu* (^{o}C)					
		27-May	–	–	–	–	–	–
		4-Jun	1170	1240	1250	1180	1270	1200
		15-Jun	1010	1160	1130	1090	1140	1100
		27-Jun	1030	1070	930	1060	1100	990

CHAPTER IV

Table C-1. Average soybean seed yield for each fertilization treatment within site-year from 2011 to 2013 in Oklahoma.

			Seed yield			
			Stillwater			Perkins
TRT	Fertilizer rate	Application method	2011	2012	2013	2013
			kg ha^{-1}			
1	5.7 Kg N ha^{-1}	in furrow	2594	2087	2060	1725
2	22.4 kg N ha^{-1}	broadcasted	2449	2554	2166	1735
3	1.2 l Bioforge ha^{-1}	foliar at V4	2781	3245	2299	1704
4	1.2 l Sumagreen ha^{-1}	foliar at V4	2727	2690	2130	1455
5	0.6 + 0.6 l Nutrivant ha^{-1}	foliar at V4 / R2	2111	2742	2054	1708
6	1.2 l Nutrivant ha^{-1}	foliar at R2	2342	2755	2310	1693
7	No fertilization	—	2576	2770	2214	1687

CHAPTER V

Table D-1. Average seed yield for each maturity groups, row spacing, and seeding rate under irrigation conditions in Stillwater, OK.

Maturity group	Row spacing	Seeding rate	Seed yield 2011	2012	2013
	cm	Seeds ha^{-1}	————	Kg ha^{-1}	————
4.8	19	247,000	1549.897	3716.131	2250.236
		346,000	1577.355	3461.014	3239.644
		445,000	2432.349	2338.581	3418.892
	76	247,000	1746.123	3133.642	2417.189
		346,000	1877.552	3072.317	2514.713
		445,000	2843.313	3157.76	2399.085
5.6	19	247,000	1622.181	—	1569.589
		346,000	1311.983	3295.596	1572.357
		445,000	2032.733	2615.416	2226.387
	76	247,000	1354.896	2112.682	1922.267
		346,000	1659.523	2400.905	2129.035
		445000	2117.623	2297.291	1821.696

VITA

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